Practical Air Navigation

Frontispiece.—The globe represented by series of Mercator and Lambert projections.
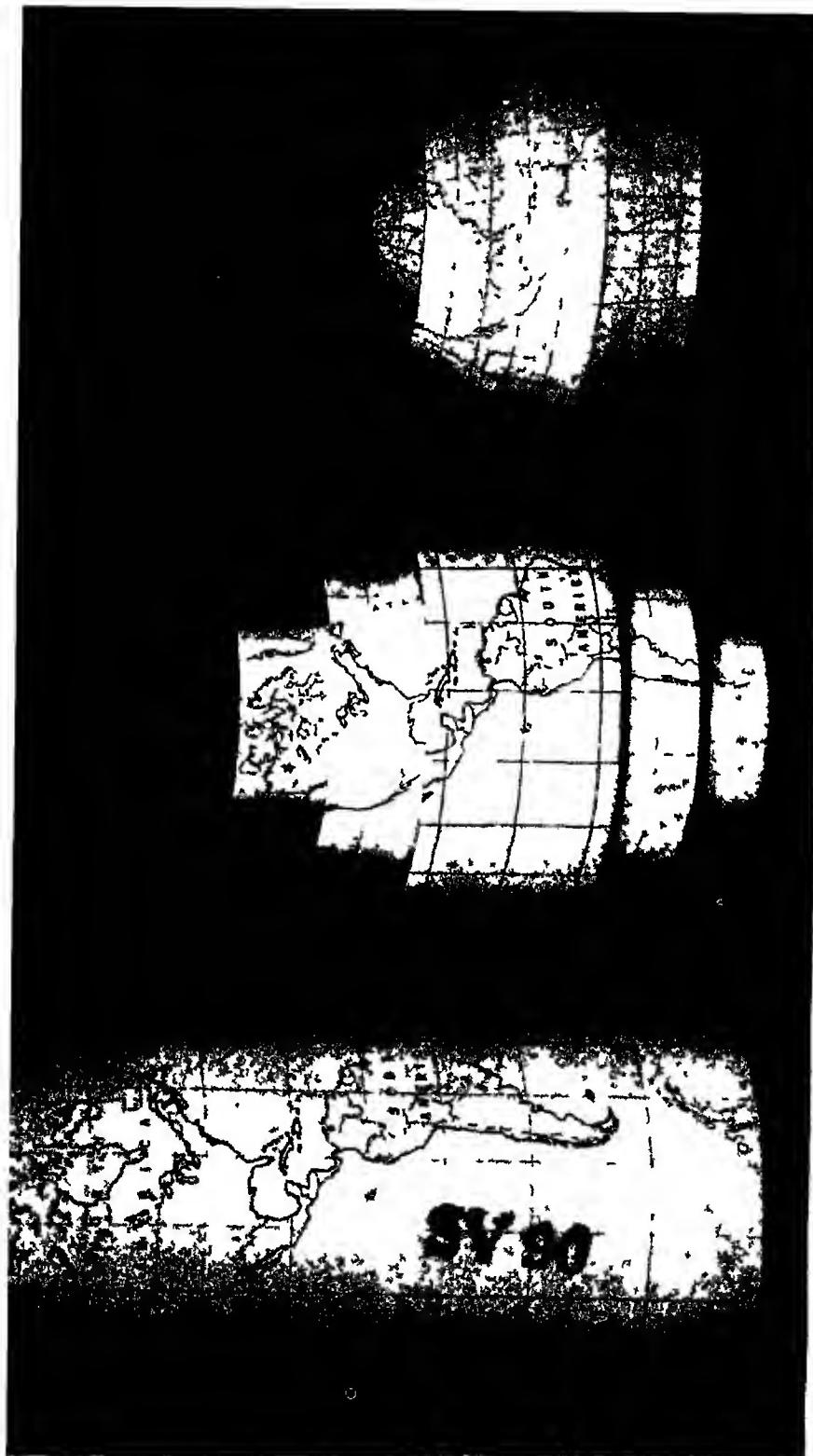
PREFACE

This second edition of Practical Air Navigation as Civil Aeronautics Bulletin No. 24 is, in effect, its fifth edition, the first three editions having been issued as Special Publication No. 197, of the U. S. Coast and Geodetic Survey. It has again been completely revised by the original author, Thoburn C. Lyon, Chief Cartographic Engineer, Aeronautical Chart Branch, U. S. Coast and Geodetic Survey.

The present revision has benefited greatly from the wide use of this text in the controlled courses of the War Training Service of the Civil Aeronautics Administration, and in the training programs of the armed forces. All material has been completely revised, and several new chapters have been added, bringing the work, as far as possible, abreast of recent developments. Considerations of national security at the moment prevent more than a casual reference to certain methods and equipment already available.

In the preparation of this revised edition, acknowledgment is given to personnel of the Ground School Section of the Standards Division, CAA War Training Service, for their active assistance. The author has had the full cooperation of other officials and personnel in the Civil Aeronautics Administration and the United States Coast and Geodetic Survey. Valuable assistance has also been received from members of the armed forces and from some pilots and officials in private industry. It is believed that their combined cooperation will make this book of greater service in the development of practical air navigation.

After the completion of manuscript for the present edition, circumstances prevented its printing for some months. The delay has made it possible to revise certain portions of the text (particularly the portions pertaining to charts) up to March 1945, but the greater part of the book should be considered as of May 1944.

CONTENTS

Chapter I.—THE PROBLEMS OF AIR NAVIGATION

Chapter II.—THE EARTH: ITS FORM AND FEATURES

Chapter III.—CHART PROJECTIONS FOR AIR NAVIGATION

Chapter IV.—INSTRUMENTS

Chapter V.—CHART READING

Chapter VI.—DEAD RECKONING

Chapter VII.—SPECIAL PROBLEMS OF DEAD RECKONING

Chapter VIII.—AIR NAVIGATION COMPUTERS

Chapter IX.—RADIO NAVIGATION

Chapter X.—CELESTIAL NAVIGATION

Chapter XI.—NORTH POLAR NAVIGATION

Chapter XII.—THE PRACTICE OF NAVIGATION

Chapter XIII.—APPENDIX

PRACTICAL AIR NAVIGATION

Chapter I.—THE PROBLEMS OF AIR NAVIGATION

FLIGHT ITSELF

Learning to fly has occupied the minds of men almost from the beginning of time. Legend has brought us accounts of magic carpets and winged sandals; history brings us stories of flying machines that might have succeeded with proper powerplants or other refinements; but the first powered flight in a heavier-than-air machine was made at Kitty Hawk, N. C., by Orville Wright, on December 17, 1903.

That first flight lasted for 12 seconds, and covered a distance over the ground of only 540 feet. The maximum altitude attained was 12 feet above the ground. Today, light airplanes, refueled in flight, have remained in the air an entire month; the long-distance record is in excess of 6,000 miles; and commercial transportation has reached into the lower layers of the stratosphere.

THE AIRCRAFT

In the early days of flying, serious accidents often occurred because men were not thoroughly familiar with this new medium of transportation. Its mechanical limitations were sometimes not realized, and maneuvers were attempted which were beyond its structural strength and performance. The functioning of controls under unusual conditions had to be learned the hard way, and recovery from spins and stalls could be learned only by trial and error.

Today pilots are expected to be thoroughly familiar with the construction of the aircraft, its controls, and its limitations. Competent instructors are available to impart this information, as well as to give actual flight instruction. Manuals treating of the airplane, its powerplant, and the various flight maneuvers, have been prepared by the Civil Aeronautics Administration. These manuals are based not only on sound theory, but also on long experience. They should be obtained and carefully studied.

AIDS TO NAVIGATION

The achievement of flight, notable as it was, satisfied only half of the age-old dream. To satisfy the other half, it was necessary that men learn to fly expeditiously from *here* to *there*, cutting across all barriers and surface limitations. The directing of aircraft from one place to another by various methods is the science of air navigation.

In bad weather and in the hours of darkness, the usual landmarks are often lost to view. If air transportation is to function safely at such times, some artificial aids to navigation must be made available.

To supply this need, rotating beacon lights have been established at frequent intervals along the Nation's airways, of which there are some 35,000 miles (1944). Many of these lights have their own characteristic signals, by means of which pilots may definitely identify them and determine their own positions. Figure 1 is a photograph of a typical airway beacon light; figure 2 shows the complete beacon installation. The power shed at the base of the tower is air marked with the site number of the beacon, for identification from the air by day. Where there are no suitable airports, landing fields have been constructed at intervals of about 50 miles along the airways for use in case of emergency.

Figure 1.—Rotating aeronautical beacon light.

In very thick weather all visual aids become useless, and for this condition the various radio aids have been developed. Radio range stations transmit directional signals along the airways, while low powered nondirectional radio beacons also furnish guidance or indicate critical points along the routes marked out by the range stations. At scheduled intervals weather information and other data of importance to those flying the airways are broadcast from the radio range stations. Figure 3 shows a typical radio range station.

With the installation of instrument landing systems at the principal terminals, and with other instruments now in process of development, we

Figure 2.—Rotating beacon installation.
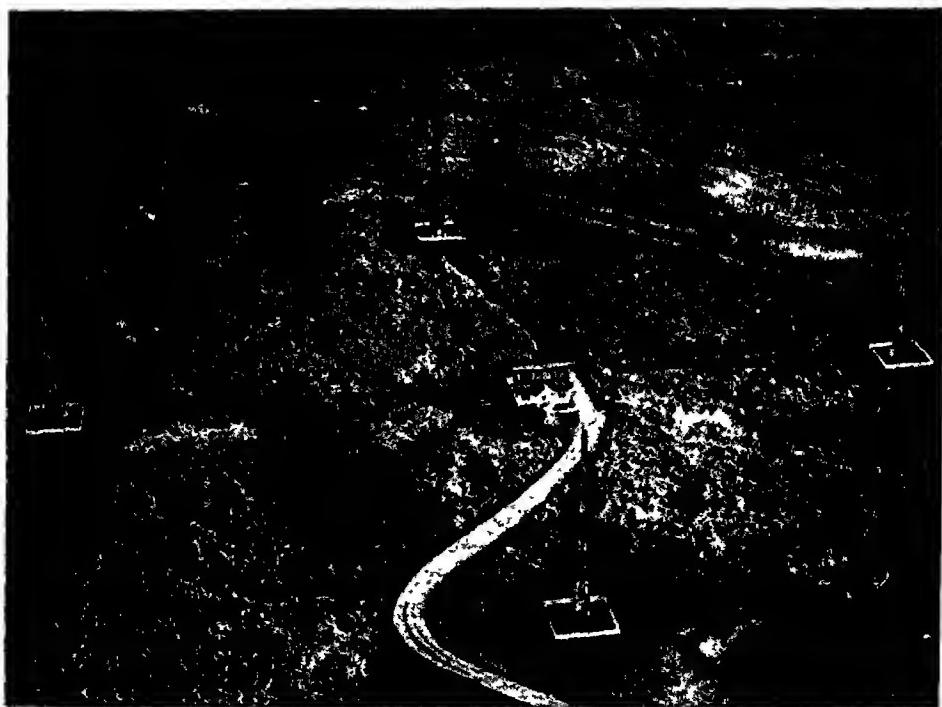
Figure 3.—Radio range station.

may confidently expect that in the near future air transportation will become independent of all but the most severe weather conditions.

WEATHER

In air navigation, as at sea, weather constitutes one of the most serious problems—all the more so because an aircraft cannot "lie to" until the weather has cleared, but must maintain flying speed in one direction or another. Contrary to the classic complaint of Mark Twain, something has been done about weather for the air navigator.

At a great number of stations along the airways and also at a number of off-the-airways stations, complete weather observations are made four times a day and are transmitted to weather forecast centers by telephone, telegraph, radio, and thousands of miles of teletype circuit. When entered on the weather maps and properly evaluated, a complete picture of the Nation's weather at the time of the observations is presented. By comparing successive weather maps, the *movement* of weather over the Nation's airways may be traced. Meteorologists are available to supply this picture to pilots before the beginning of flight, and as the flight progresses any changes of importance are broadcast by radio.

This complete weather service results not only in greatly increased safety over the Nation's airways, but also in a higher percentage of completed flights.

AIR TRAFFIC CONTROL

The increase of air traffic through the years made it increasingly necessary that some form of traffic control be set up for the safety of all. The control of air traffic has developed into two types—control by regulations and procedures, and control by ground agencies.

The basic rules for the regulation of air traffic are the "Air Traffic Rules." Since these rules are written in legal language, they are explained and clarified in a handbook called Civil Aeronautics Manual 60. In addition, the airport management at an airport issues "Field Rules" governing activities on and about the airport. These generally include standard traffic and taxi patterns which describe the paths traffic must use in flying locally and taxiing on the airport. The "Air Traffic Rules" and local "Field Rules" constitute the "rules of the road" for the pilot.

Civil Air Regulations specify two types of rules for flight in different weather conditions—"Contact Flight Rules" and "Instrument Flight Rules." Contact Flight Rules concern flights made in weather conditions where a pilot can conduct his flight by reference to the ground or water at all times, can clearly see and identify other aircraft and landmarks at a distance of at least 3 miles (for flight along the airways), and maintain a minimum distance of at least 500 feet* above or below and 2,000 feet horizontally from all cloud formations. Instrument Flight Rules govern flights made in closer proximity to cloud formations or in weather condi-

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* These requirements have been modified under revised Civil Air Regulations, effective August 1, 1945.

tions worse than those prescribed for Contact Flight Rules. A pilot, about to make an instrument flight, is required to file a "flight plan," giving all the details of his proposed flight, and to receive approval prior to departure.

Ground agencies engaged in air traffic control are of two kinds—one controlling traffic in the immediate vicinity of an airport and the other controlling aircraft operating on instrument flight plans along the airways between airports. An airport traffic control tower is located on top of a hangar or building on the edge of an airport and is operated by the airport management or by the Civil Aeronautics Administration (when re-

Figure 4.—Airport traffic control tower
at Washington National Airport.

quested by the War or Navy Departments). These control towers are operated at airports where traffic congestion is so great that traffic and taxi patterns and the rules of right-of-way are not sufficient for safe flying. A control tower has jurisdiction over all aircraft moving on the airport or flying within 3 miles of the airport. It is understood that this control may soon be extended to 5 miles. Instructions to pilots are issued by two-way radio or by varied lights. Figure 4 shows a typical airport traffic control tower; figure 5 is an interior view of a typical installation.

The civil airway system is divided into 25 airway traffic control areas, each consisting of about 1,500 miles of airways. In each area a central

office, called an airway traffic control center, has jurisdiction over all aircraft flying in instrument weather conditions. Each center has a network of interphone (private telephone) lines connecting it to all the voice radio stations within its area, through which it receives flight plans and reports from aircraft in flight and issues instructions and flight plan approval. The center controls traffic in such a manner that when the pilot of an instrument flight maintains the course and altitude he has been instructed to fly, danger of collision with other aircraft is minimized, and delay en
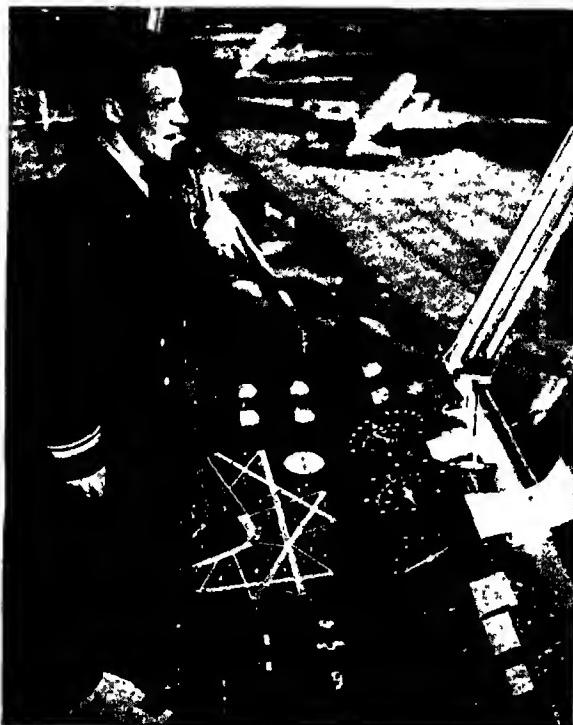
Figure 5.—Interior of Washington National Airport traffic control tower.

route is reduced to the minimum consistent with safety. Figure 6 shows a typical airway traffic control center. As air traffic grows in volume, air traffic control becomes of ever-increasing importance.

COMMUNICATIONS

In the early days of aviation, most pilots preparing to make cross-country flights obtained the desired flight information commercially, or took off without knowledge of conditions ahead. Usually the latter was the case, as the sources of reliable flight information were few and the time required was prohibitive. During flight no communications with ground facilities were maintained and pilots often flew into dangers which they might have avoided if satisfactory air-ground communication had

been available. This resulted in a high accident rate for this type of flying.

With the development of air transportation it became apparent that only a specialized system of airway communications connecting landing areas and important weather reporting points would enable pilots to secure reliable and current weather and other flight information prior to their departures. It also became obvious that ground radio facilities would have to be provided in order for pilots to receive by radio, while in flight, cur-
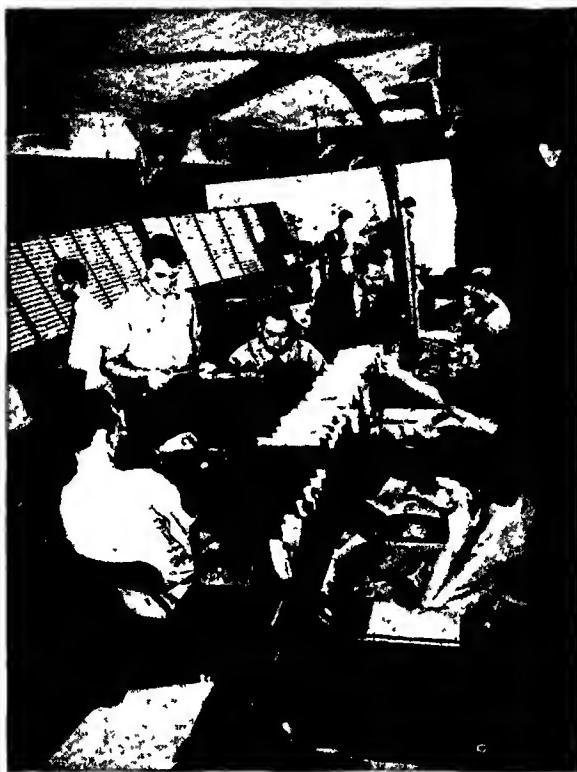
Figure 6.—Typical airway traffic control center.

rent information and instructions which would assist them to complete their flights with safety. The problem of aviation communications was primarily interstate in nature, and appropriate facilities were provided by the Federal Government as the needs developed.

Along the 35,000 miles of civil airways there are now well over 400 airway communications stations. These stations (identified for radiotelephone purposes as "Fort Worth Radio," "Kansas City Radio," etc.) are spaced along the airways at intervals so as to provide the necessary receiver density. Some are located at terminal airports, and others at intermediate points between centers of population. For the dissemination of weather and other flight information to all aviation interests, a network of 70,000 miles of teletype lines links airway communications stations with

each other, and with some 220 weather reporting points. Figure 7 is an interior view of a typical airway communications station; figure 8 shows the broadcast booth at the station.

Aircraft communicators at these stations provide pilots with the latest weather reports, forecasts, information on field conditions, and other flight information that will assist them in planning and conducting safe and efficient flights. This information is furnished to pilots calling at the stations for this purpose, and is furnished, via radio, to pilots as their flights progress. In addition, aircraft communicators relay traffic control instruc-
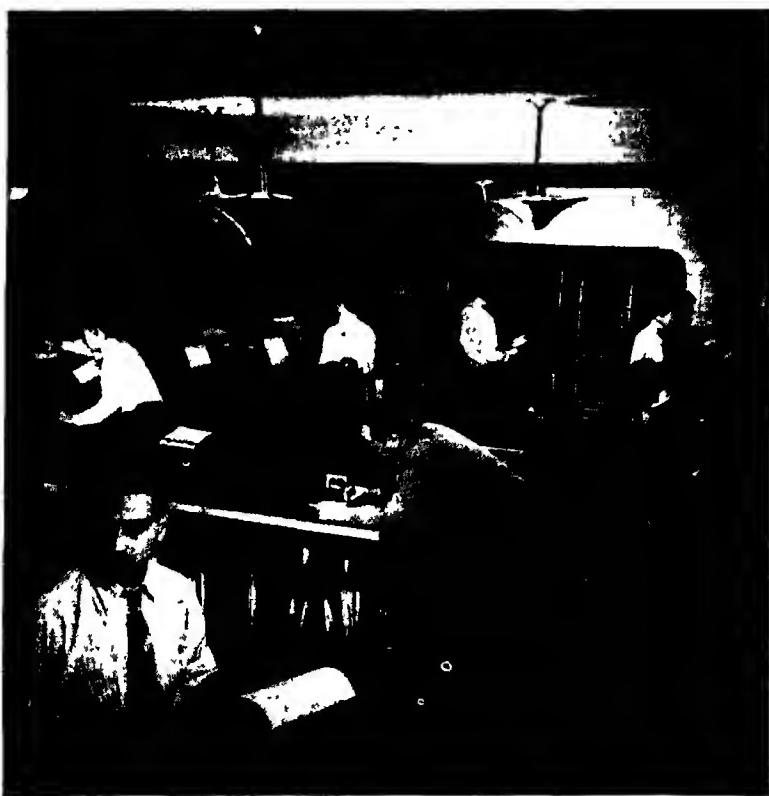
Figure 7.—Interior of a typical airway communications station.

tion by radio, from airway traffic control centers to the pilots for whom the instructions are intended.

With the reliable information thus made available, pilots may now plan their flights with confidence, and may be sure of obtaining, in flight, by air-ground radio, the latest pertinent information. If hazardous conditions develop ahead, they may expect to receive warning before the hazards are encountered. They will receive instructions, relayed through the communications stations, intended to prevent their collision with other aircraft. Also, if they become lost or otherwise involved in an emergency they may utilize the air-ground radio to request and receive emergency assistance.
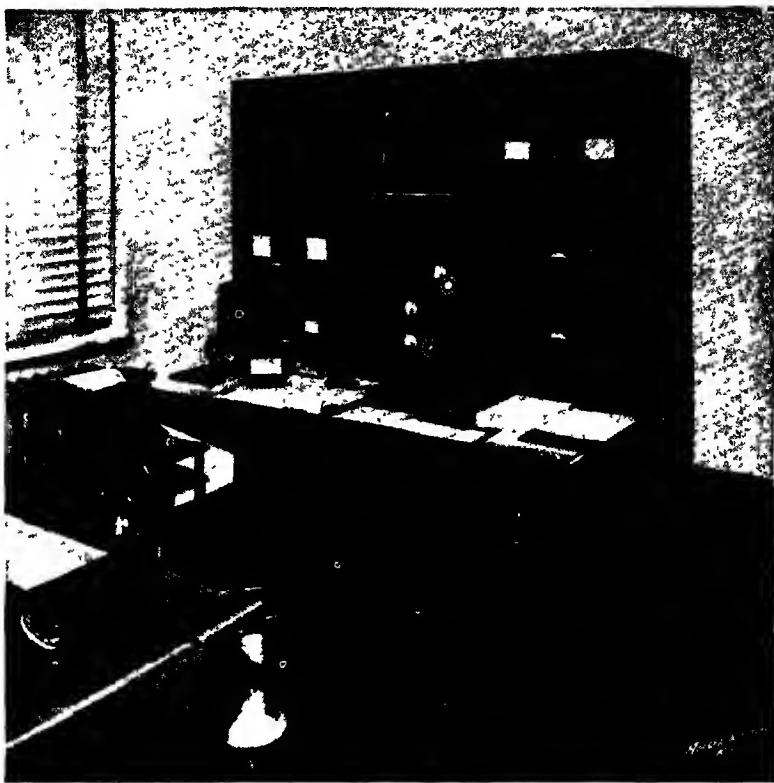
Figure 8.--Broadcast booth at an airway communications station.

CHARTS

The most elaborate system of aids to navigation is of little value unless the navigator is provided with charts showing the locations of the various aids with reference to other features of the surface.

In the early days of surface navigation, mariners soon learned the value and importance of charts; even in the barnstorming days of aviation, pilots began to realize this same need. Because of the basic similarity between nautical and aeronautical charts, the task of charting the airways was assigned to the U. S. Coast and Geodetic Survey, with instructions "to provide as adequate charts for air navigation as it now provides for ocean navigation."

With only normal head winds, some of the light airplanes make good over the ground speeds as low as 50 or 60 miles an hour. On the other hand, the speed of some of the faster military ships approaches 500 miles an hour. The pilot of the light airplane flies mostly by reference to visible landmarks; he therefore requires a large scale chart showing landmarks in all possible detail. At 500 miles an hour pilots have no time to look for any but the most prominent landmarks, and a small-scale chart showing few details is desired.
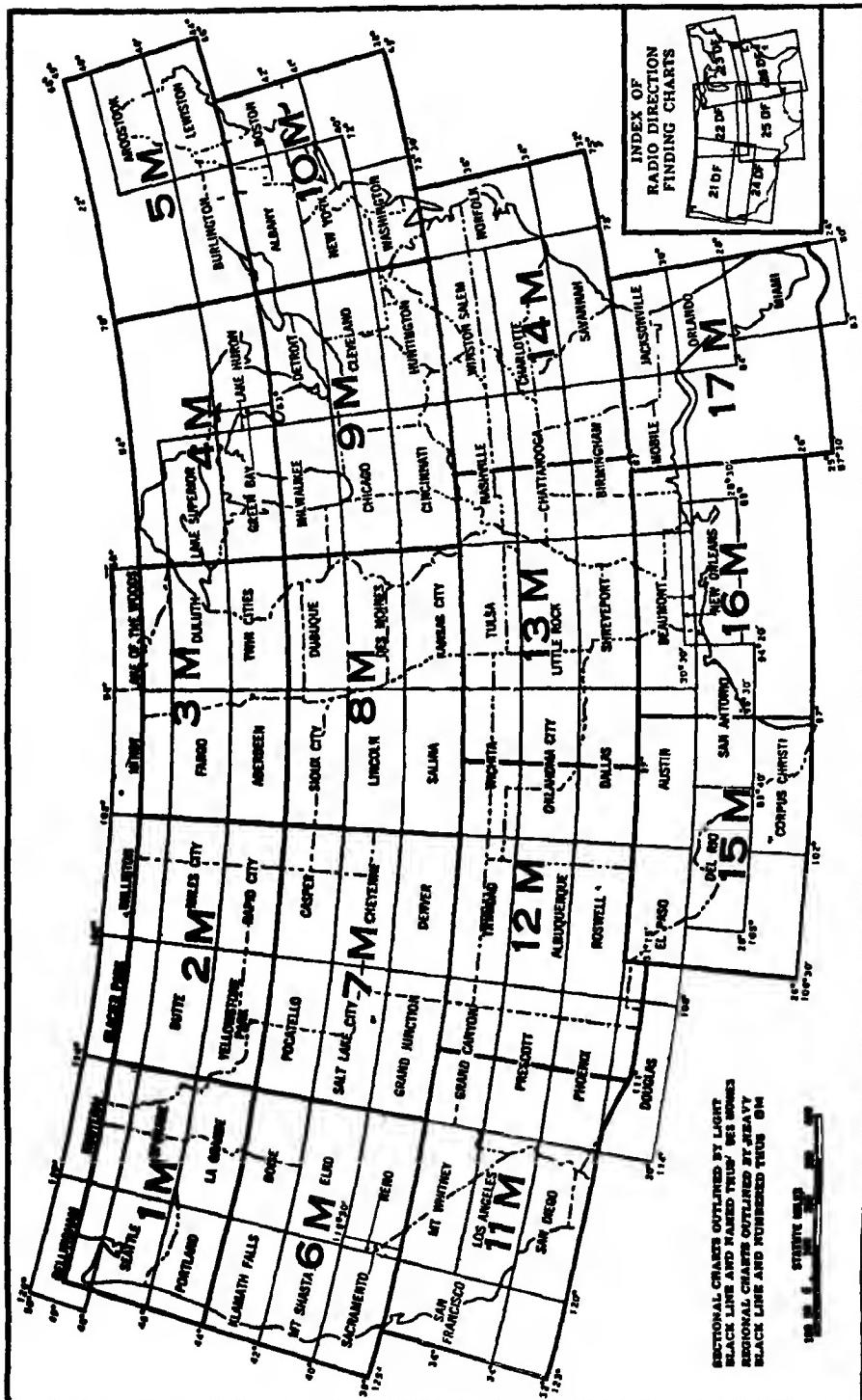
Figure 9.—Index of aeronautical charts of the United States.

To meet the varied needs of civilian pilots flying widely different types of airplanes, a number of different series of charts are required, which, from the smallest scale to the largest, are as follows:

1. Planning charts at a scale of 1:5,000,000, or about 80 miles to the inch, for a first lay-out of long routes. One chart covers the entire United States; another covers all of Alaska and extends down the west coast of Canada to include the northwestern corner of the United States. A series of 43 planning charts covering the entire world has been prepared for the use of the Air Forces, which will probably be made available to civilian pilots with the coming of peace.

2. Radio direction finding charts, at a scale of 1:2,000,000, or about 32 miles to the inch. Six charts cover the entire United States, with wide overlaps; see inset, figure 9.

3. Regional charts, at a scale of 1:1,000,000, or about 16 miles to the inch; for navigation or piloting. Only 17 charts about 33 x 50 inches are required for the United States, 10 for Alaska; see figures 9 and 10. This series will be extended to cover the Hawaiian Islands and the Philippines.

4. Sectional charts, at a scale of 1:500,000, or about 8 miles to the inch; primarily for landmark flying (piloting). The entire United States is covered by 87 charts; see figure 9.

5. Local charts, at a scale of 1:250,000, or about 4 miles to the inch; for fuller detail as terminals are approached in highly developed metropolitan centers; also, for more complete landmark detail for local flights by light-plane pilots.

6. Airport charts, at a scale of about 1:126.720 (2 miles to the inch); for complete details of landmarks and obstructions in the vicinity of an individual airport, with the correct procedure for instrument approach. The back of each chart carries details of the landing area, at about 1:18,000 (1,500 feet to the inch).

Because of the increasing speeds of aircraft engaged in this type of flying, the scales of these charts are being changed to 1:250,000 for the approach chart, and about 1:31,680 (one-half mile to the inch) for the landing chart.

In addition to the foregoing, a number of special-purpose charts have also been provided, such as:

7. Magnetic, or isogonic charts, showing lines of equal magnetic variation, at a scale of 1:5,000,000, or smaller.

8. A great-circle chart of the United States, at a scale of approximately 1:5,000,000.

9. A series of outline charts, 8½ x 11 inches, showing radio facilities at a scale of 1:2,500,000 for instrument flying along the airways; issued by the Information and Statistics Service, Civil Aeronautics Administration. These are bound together in a booklet entitled "Air Navigation Radio Aids," which is revised and printed at frequent intervals.

To illustrate further the effect of airplane speeds on the scale of charts, the average sectional chart is about 20 by 42 inches in size. With
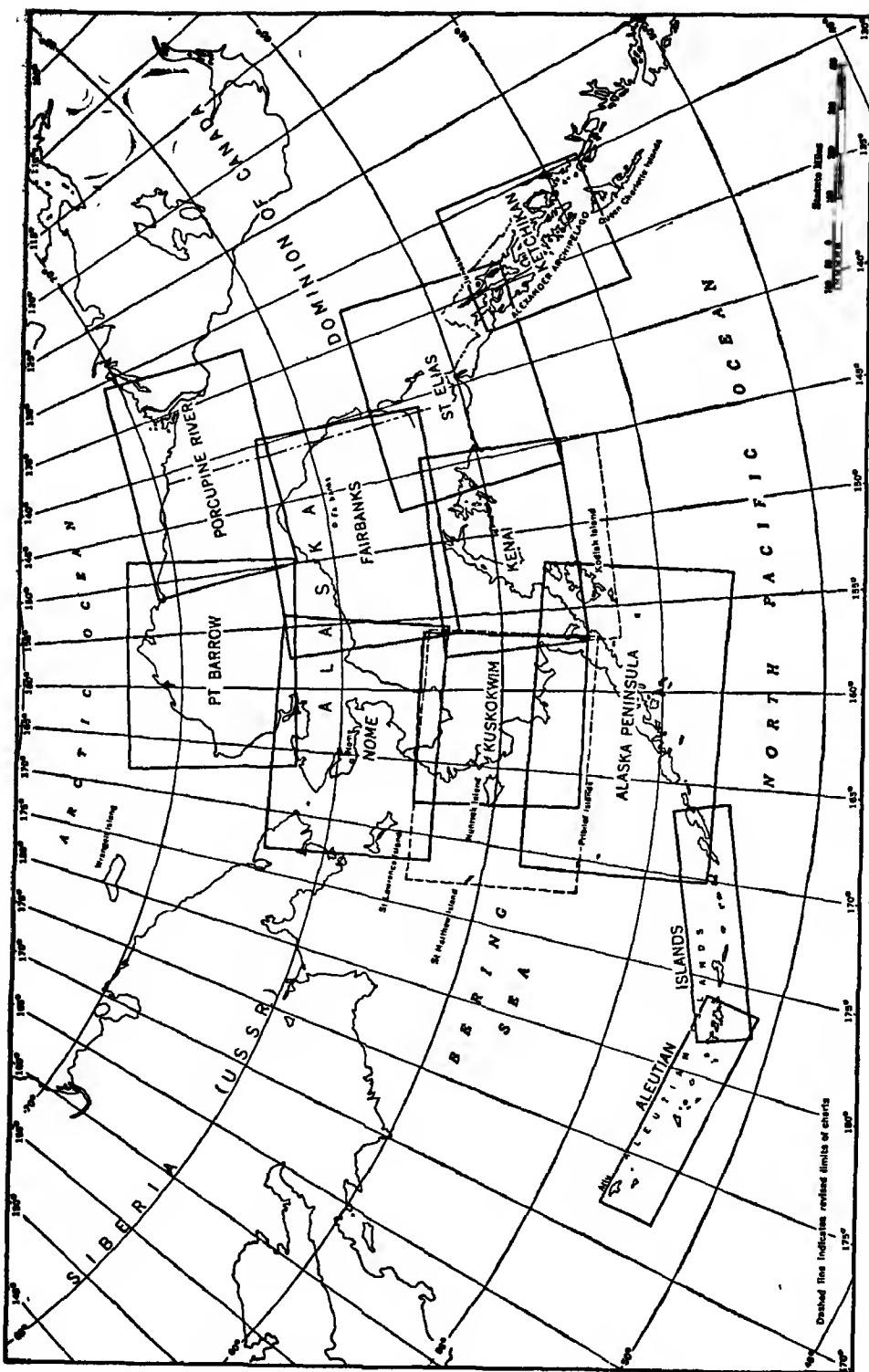
Figure 10.—Index of aeronautical charts of Alaska.

some allowance for margins, then, a sectional chart covers an area of about 140 miles from north to south, and 320 miles from east to west. At 70 miles an hour, it would take 2 hours to fly from north to south over the area represented on the chart, and about 4½ hours to cross it from east to west. At 200 miles an hour these are reduced, respectively, to 40 minutes and 1½ hours. For a flight of considerable distance, this would require the carrying of a great number of charts, with frequent changes from one chart to the next. At 400 miles an hour, the time intervals are further reduced to 20 minutes and 45 minutes. For a regional chart, at 200 miles an hour the corresponding time intervals are 2 hours and 8 hours, respectively.

The aeronautical planning charts are useful in planning routes between distant points.

The radio direction finding charts have been designed especially for use in the plotting of radio bearings. Their smaller scale and wider extent make it possible to plot bearings from radio stations that would frequently be outside the limits of a larger-scale chart.

The regional charts were designed particularly for comparatively long flights, with faster planes. For this purpose they are more convenient than the sectional charts, since pilots do not need to change charts as often while in the air. They are also convenient for planning routes which extend beyond the limits of a sectional chart, one regional chart often covering a route which would require two or three sectional charts.

The sectional charts are entirely suitable for all forms of navigation, but are intended primarily for use in pilotage. Because of their larger scale and more complete information, they are necessary supplements to the regional charts. They will always be required for detailed studies of an area, and should generally be used whenever pilotage is employed. Much of the landmark information appearing on the sectional charts has been eliminated from the regional charts, since, for their intended purpose, clarity is more essential than completeness of detail, and emphasis is placed on the landmarks of major importance.

Pilots of fast military aircraft liked the scale of the regional charts, but objected to the large paper size. They also required more landmark detail than had been shown on the regional charts. To provide for their special needs, a series of charts at a scale of 1:1,000,000, with uniform paper size of 22 x 29 inches, has been prepared for practically the entire world. They have become well liked, and were adopted by the International Civil Aviation Conference in Chicago in November 1944. A civil edition of these charts covering the United States will be issued by the Coast and Geodetic Survey by the summer of 1945. It is possible that they may in time replace the regional charts. Figure 11 shows the arrangement and numbers of charts of this series and also (in broken lines) the limits of the regional charts.

The great-circle chart is chiefly of value for one special purpose: the easy determination of the exact great-circle route between any two points.
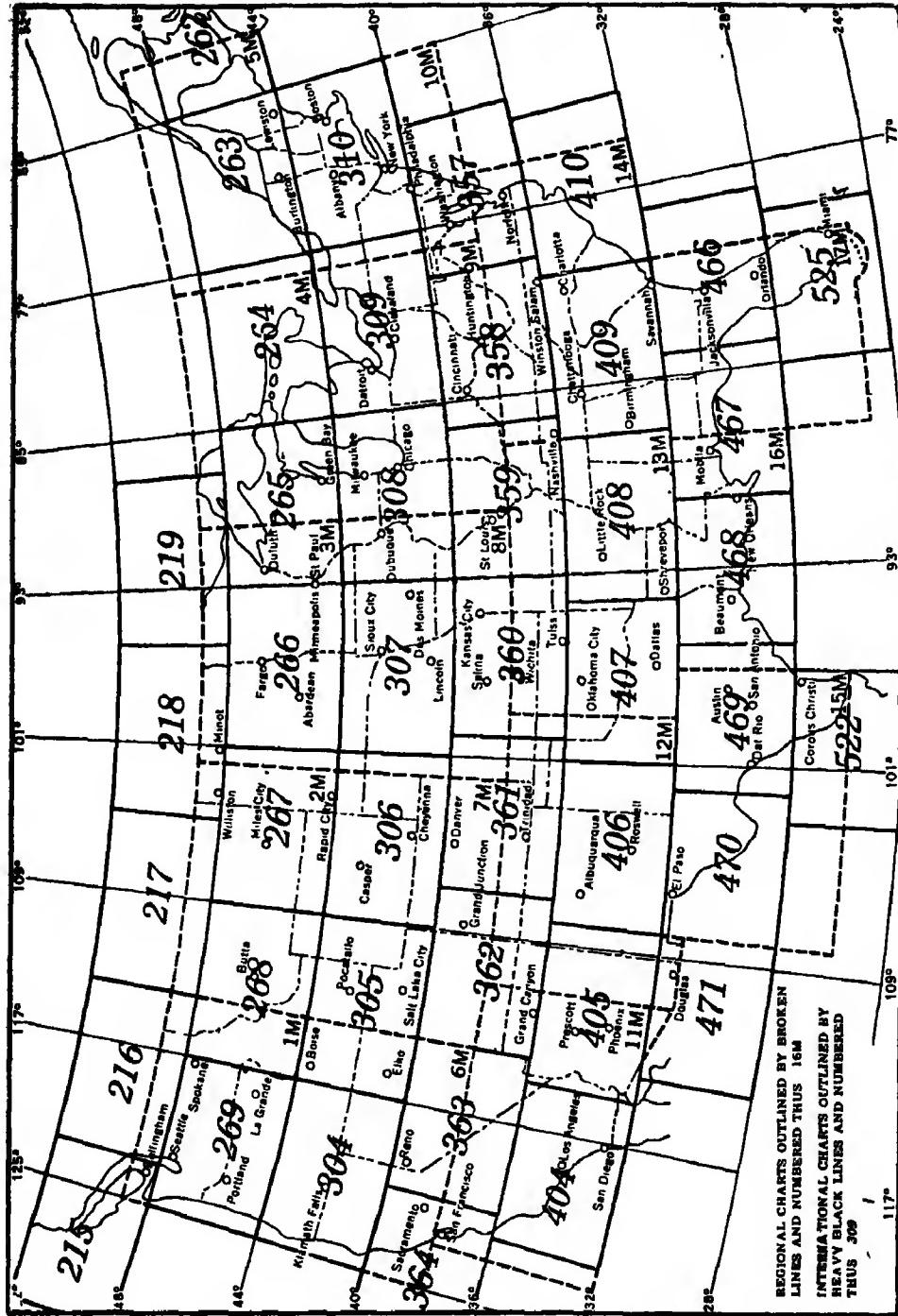
Figure 11.—Index of international series of aeronautical charts of the United States.

It cannot be used directly for the scaling of courses or distances. Its use is generally limited, then, to the most exacting record flights, and to comparative studies.

Plates I to IV represent portions of a planning chart, a radio direction finding chart, a regional chart, and a sectional chart, respectively. The special features and uses of the charts are treated more fully in later chapters.

Any of the civilian charts described, except those included in Air Navigation Radio Aids, may be obtained from the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C.; see page 343.

The same series of charts provided for civil aviation have also proved adequate for the basic needs of military aviation. In addition, to meet the special needs of the Air Forces, "long-range navigation charts" have been prepared on the Mercator projection, at a scale of 1:3,000,000 (about 48 miles to the inch) on the central parallel of each chart.

The approach charts of the Army Air Forces, scale 1:250,000, are designed for the use of air units in cooperation and coordination with ground forces. It is important, therefore, that more complete details of the terrain be included than are required for a chart intended solely for aeronautical purposes.

Essentially the same series of charts are required by the Navy, but because of their specialized problems, different scales have been chosen, and the Mercator projection is used. The following differences may be noted:

Planning charts for naval aviation are designed to cover a given strategic area, rather than to fit into some uniform index or scheme of charts. As a result, they are of varying scales, from 1:5,000,000 to 1:10,000,000.

Their long-range navigation charts are at scales of 1:2,190,000 (about 30 nautical miles to the inch) or 1:2,920,000 (about 40 nautical miles to the inch).

Their flight charts provide much greater overlaps.

Approach charts of the Navy differ only slightly from those of the Army Air Forces or the local charts of civilian pilots, the scale in this case being 1:219,000, or about 3 nautical miles to the inch.

Landing charts are comparable to civilian airport charts, but are of slightly smaller scale (1:36,500).

FINDING THE ANSWERS

With an airworthy craft, suitably equipped airways, a dependable weather service, and adequate charts, the only remaining problem is the actual conduct of flight—the art or science of directing the aircraft from *here* to *there*. The National Advisory Committee for Aeronautics has defined air navigation as "the art of determining the geographical position, and maintaining desired direction, of an aircraft relative to the earth's surface."

Through the centuries there have evolved four principal or basic methods of surface navigation. Air navigation, of course, has profited by these centuries of experience. The evolution in this case has been much more rapid, but essentially the same four methods are used. They may be briefly described as follows:

Pilotage, in which the airplane is directed with reference to visible landmarks;

Dead reckoning, in which the distance and direction are determined between two known positions, or in which position is determined from a record of the distance and direction from a known position;

Radio navigation, or the determination of position by means of observed radio bearings or distances; and

Celestial navigation, in which position is determined by means of sextant observations of the sun, moon, planets, or stars, together with the exact time of the observations.

No one of these methods may be considered as sufficient by itself. Instead, all are often used on a single flight, successively or in combination, according to the needs of the particular situation.

The term "avigation" has occasionally been suggested as being more appropriate than "navigation," since it pertains more to the flight of a bird (avis) than to the course of a ship (navis). The modern science of air navigation has little in common with the flight of a bird, and the principles of navigation are the same whether applied aboard a surface ship or a ship of the air. The National Advisory Committee has therefore noted that this term is considered unnecessary and undesirable.

QUESTIONS

1. Why is it important that private pilots be familiar with the construction of aircraft?

2. To what extent do the Civil Air Regulations affect private pilots?

3. Define navigation.

4. What use might be made of the various aids to navigation when flying by reference to visible landmarks?

5. Outline the general provisions for furnishing weather information to pilots.

6. Name the principal series of aeronautical charts published by the United States Coast and Geodetic Survey for civil aviation.

7. State the general purpose of each series of charts.

8. Name three special-purpose charts, with a general description of each.

9. With a cruising speed of 100 miles an hour, how long would it take to cross the area covered by an average sectional chart: (a) from north to south? (b) from east to west? If a regional chart were used, how long would it take?

10. Under what circumstances should a sectional aeronautical chart be used? For what purpose should a regional chart normally be used?

11. State two important reasons why the sectional charts for a route should also be at hand, even though a regional chart is being used in navigation.

12. What additional kinds of charts are required by the Army Air Forces for military purposes?

13. The approach charts of the Army Air Forces are the same scale as the local charts prepared for civil aviation. How and why do they differ?

14. What are some of the chief differences between the aeronautical charts of the Navy and those provided for the Army and civilian use?

15. Name and define the four general types of navigation.

Chapter II.—THE EARTH: ITS FORM AND FEATURES

THE EARTH AS A PLANET

In all forms of navigation, some elementary knowledge of the earth, upon the surface of which the navigator works his problems, is important.

The earth is one of the family of nine known planets and a number of satellites and lesser bodies which revolve about the sun and make up the solar system, being third in order from the sun.

Only four of the nine planets are of interest in navigation: Venus, Mars, Jupiter, and Saturn. Mercury is so close to the sun that observation is difficult, and many professional astronomers have never seen it. Uranus and Neptune are so far away that they are too faint for navigational use. Our moon is considered only as a satellite of the earth, rather than one of the planets.

The sun is our nearest star. It is a great mass of flaming gas, some 864,000 miles in diameter, which is quite small as compared with many of the other stars. It is our chief source of light and heat, the amount received from any other source being negligible by comparison. The sun appears bigger and brighter than the other stars only because it is so much closer to us, its average distance being about 93,000,000 miles. At this distance, its light (which travels more than 186,000 miles a second) reaches us in about 8 minutes. The next nearest star is so far away that its light requires $4\frac{1}{3}$ years to reach us; that is, more than 25 trillion miles.

PRINCIPAL PHYSICAL FEATURES OF THE EARTH

More than 70 percent of the earth's surface is covered by water. The Pacific Ocean alone covers half the earth, averaging about 14,000 feet in depth. The greatest ocean depth yet measured, northeast of Mindanao in the Philippine Islands, is 35,410 feet.

The land surface of the earth is made up principally of five large continents: North America, South America, Eurasia (Europe and Asia together), Africa, and Australia. The continental masses extend outward under the sea with only gentle slope and moderate depth to form the "continental shelf," before falling off into ocean depths.

The antarctic land is sometimes referred to as the "Antarctic Continent," and occasionally Greenland is called a continent. The latter is generally considered as an island, however; often as a part of North America. Scattered islands, some of considerable extent, make up the remainder of the earth's land area.

North America is separated from Asia only by the narrow Bering Strait. It is joined to South America by the Isthmus of Panama. The United States, exclusive of possessions, takes up only a little more than 3,000,000 square miles of North America's 9,000,000 (approximately), or about one-third. The following table affords, in round numbers, interesting comparisons with other countries.

TABLE 1.—*Area and population of some of the principal countries of the earth*

Country	Area (sq. mi.)	Population
United States	3,025,000	130,000,000
United States and possessions	3,738,000	142,000,000
China	3,756,000	423,000,000
Great Britain	94,000	47,000,000
Great Britain and possessions	13,355,000	500,000,000
U.S.S.R. (Russia)	8,073,000	166,000,000
Germany	225,000	77,000,000
Japan	148,000	70,000,000
Japan and possessions	263,000	100,000,000

When viewed on a map such as figure 39 it appears that North America is widely separated from Europe and Asia. When viewed on a map such as figure 13, or on a globe, it is seen that this is not the case, but the principal land masses are clustered about the pole. Many atlases still carry maps of the "land hemisphere" and the "water hemisphere." With only a few important extensions, the land hemisphere contains almost all the land surface of the earth.

While the land surface seems stationary when compared with the surging waves of the sea, it is by no means static, but is subject to continual change. Some of the changes are sudden, as in the recent elevation of a volcano in Mexico, from a level plain to a height of nearly 2,000 feet in a few months, with its rate of growth at that time undiminished. As a rule, changes are quite gradual, and are apparent only by comparison of records covering many years, or from geological evidence.

Near San Jose, Calif., an area of 200 square miles has recently shown continuously lower elevations, the "subsidence" amounting to more than 5 feet in the last 20 years. Even this is considered rapid. From geological evidence it is apparent that the entire coastal plain along the Atlantic and the Gulf of Mexico was formed beneath the sea, by sedimentary deposits. Today it has been elevated above the sea, although not as much as in former times, as attested by the submarine extension of stream valleys, cut when they were above the level of the sea. One of the best known submarine canyons is that of the Hudson River, which maintains the general characteristics of the Palisades nearly 150 miles at sea. Another submerged stream valley may be traced eastward from Chesapeake Bay to depths of about 9,000 feet.

Even the great mountain masses have been slowly lifted from earlier positions on the floors of ancient seas. This may be known from the fossil remains of marine life which they contain, and from other unmistakable evidence. Having been so elevated, natural processes such as erosion, freezing, and thawing begin to wear them down. Not the least of the wearing-down agencies is glaciation. Only a few glaciers are now to be found in the United States, but the trough-like valleys between the high peaks in the Rocky Mountains and in the Sierra Nevada are the result of their work.

In a former period, most of North America was ice-covered, including much of the northeastern part of the United States (see fig. 12). As the great ice sheet moved over the land, the surface was smoothed down into rounded parallel ridges; lake basins were scooped out of the underlying rock (see Lake of the Woods sectional chart), while great boulders were carried far away and deposited at some distant place at the edge of the

Figure 12.—Maximum extent of glaciation in North America.

melting ice. The parallel fingers of the New England coast indicate the general direction of movement of the ice sheet.

The earth's great mountain ranges seem to form an almost unbroken line through all the major continents (see fig. 13). The Andes, in South America, reach a maximum elevation of nearly 23,000 feet. Continuing northward into the United States, the highest point is Mt. Whitney, 14,496 feet above sea level. Strangely enough, the lowest point in the United

States lies less than 100 miles eastward, in Death Valley, Calif. (276 feet below sea level). In Alaska, Mt. McKinley is the highest point, with an elevation of 20,300 feet. The watershed crosses into Asia, reaching the earth's highest elevation of 29,141 feet at Mount Everest; then into Africa, where Mt. Kilimanjaro reaches 19,324 feet. Australia's highest point, Mt. Kosciusko, is 7,328 feet above sea level.

Mountains have a direct bearing not only on the economic development of a country, but upon air navigation as well. Some are so high that they cannot be cleared easily with ordinary commercial aircraft. Radio
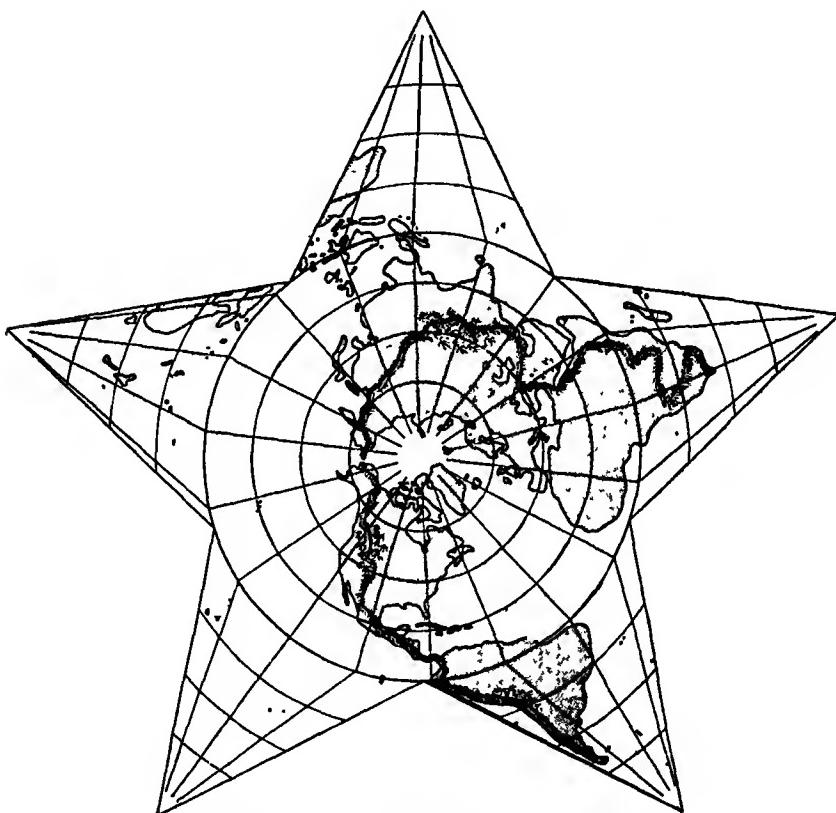
Figure 13.—Principal mountain ranges of the earth.

signals are distorted by reflection from them. Scheduled operations are often hindered by cloudiness and the excessive rainfall that results from condensation when the moist air from the sea is cooled as it is forced to higher levels. For example, on the westerly slopes of the Sierras, ten times as much precipitation occurs as on the easterly slopes. Many similar effects can be noted on any map showing the world's annual rainfall.

Earth's highest elevation (29,141 feet) plus the greatest ocean depth (35,410 feet) provides the maximum difference in surface elevation of 64,551 feet. As compared with the earth's diameter this is quite small; on a globe 1 foot in diameter it would be represented by less than one-

fiftieth of an inch, and the surface of the entire globe would appear quite smooth and spherical.

THE EARTH A SPHERE

Navigation on a flat earth would be very simple indeed. There is a common saying, however, that "the earth is round." Strictly speaking, the earth is not a sphere, but a "spheroid." It is slightly flattened at the poles, the polar diameter (7,900 miles) being about 27 miles shorter than the diameter at the equator (7,927 miles). In practice, navigation even on a spherical earth can be made quite simple, and the earth is regarded as a perfect sphere.

One of the most convincing and practical proofs that the earth is a sphere is the fact that, for centuries, navigators have plotted and sailed their courses on that assumption, and have consistently arrived at the most distant destinations. Unfortunately, many of us have obtained our impressions of distance and direction from maps of the world such as figure 39, rather than from a globe. To correct the distorted Mercator representation in areas remote from the equator, a number of recent maps have been prepared similar to the central part of figure 13. In this case there is relatively little distortion near the pole, but increasing distortion toward the equator.

From figure 13, it is apparent that the shortest route from our own west coast to Tokyo or Chungking is by way of Alaska and Siberia, not across the Pacific. The direct route between Chicago and Moscow lies over the polar regions, and it is possible that air lines of the future may follow such routes on the spherical earth. Contrary to common opinion, better flying conditions are met in the Arctic than in many areas in lower latitudes.

THE EARTH A ROTATING SPHERE

The earth travels about the sun in a great ellipse, one complete revolution in its orbit requiring a little more than 365 days (1 year). At the
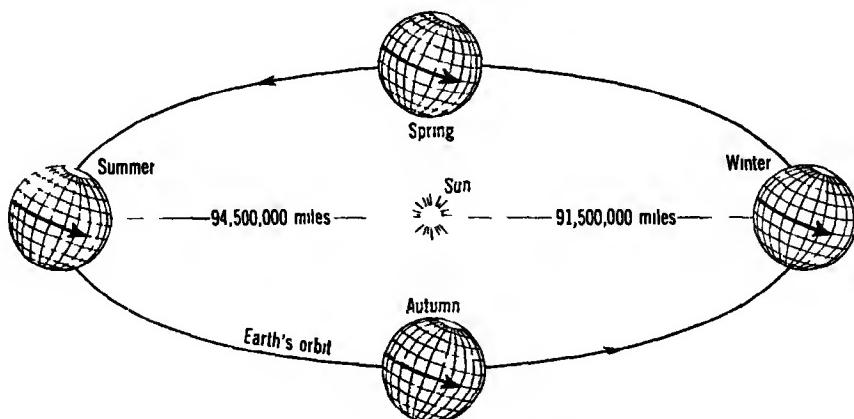
Figure 14.—The earth as a planet.

same time, it also rotates on its axis, a complete rotation with respect to the sun requiring 24 hours. The rotation of the earth causes day and night for us, according as our part of the earth is toward the sun or away from its light. *The direction of rotation is from west to east (fig. 14) and it therefore seems as though the sun, moon, planets, and stars rise in* the east and pass across the sky to set in the west.

Throughout its yearly journey about the sun the direction of the earth's axis (about 23½° from a perpendicular to the plane of its orbit) remains practically unchanged. The rotation of the earth on an inclined axis is probably the most important single fact in connection with the earth. It provides a system of coordinates for determining position, and a measurement of time; it also determines the apparent motion of the heavenly bodies, the seasons, climate, the duration of daylight at various latitudes, and the direction of the prevailing winds.

LATITUDE

On the surface of a stationary sphere all points are exactly alike, and there is no definite point to serve as the origin of a system of reference lines. As soon as rotation of the sphere is introduced (as in the case of the earth), this is no longer true.

The axis on which the earth rotates is a definite line within the sphere, different from any other diameter. The ends of this diameter, where they meet the surface of the earth, are called the poles. With these as starting points, the sphere is supposed to be divided into two equal parts by a plane perpendicular to the axis and midway between the poles. The circle formed by the intersection of this plane with the surface of the earth is also a definite line upon the earth, and is called the equator.

Any number of circles can be drawn which will pass through both poles. These circles are known as meridians. In most countries they are considered to be divided into 360°, and there will be 90° between the equator and each pole, on each side.

Let us now take a point along one of the meridians 30° north of the equator. Through this point pass a plane perpendicular to the axis and *parallel* to the plane of the equator. The intersection of this plane with the surface of the earth is called a *parallel* of latitude, this particular one being the parallel of 30° north latitude. In the same way other circles may be determined to represent other degrees of latitude north or south of the equator. The position (latitude) of any point on the sphere between the equator and the poles may now be definitely fixed as "so many degrees north or south of the equator."

LONGITUDE

The equator may also be divided into 360°, for the measurement of longitude, but first we must decide upon some starting point. A great many places have been used for this purpose by different nations. For example, many French maps are based on the meridian of Paris as the starting point, or "prime meridian." Old maps of the United States are

still found occasionally, with the longitude numbered from the meridian passing through Washington, D. C. At an early date the British adopted the meridian passing through their principal observatory at Greenwich as the origin for reckoning longitude, and this has since been adopted by many other countries.
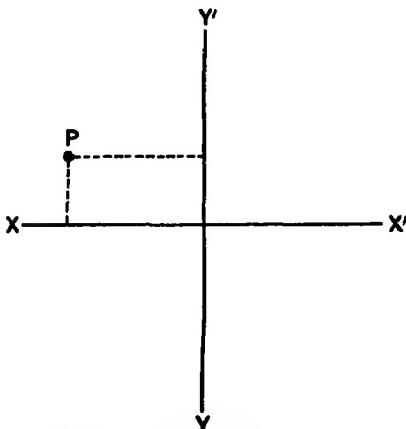
Figure 15.—The location of a point on a plane from known reference lines.
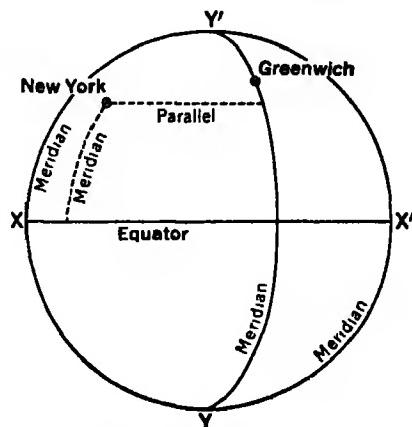
Figure 16.—The location of a point on the earth from known reference lines.

The longitude of a place may be defined in several different ways. It is:

1. The distance along the equator, measured in degrees, minutes, and seconds, between the meridian of Greenwich and the meridian passing through the place; or,

2. The distance from the meridian of Greenwich, measured along the parallel passing through the place, in degrees, minutes, and seconds; or,

3. The angle at the pole between the meridian of Greenwich and the meridian passing through the place.

Longitude is measured up to 180° east or west from the meridian of Greenwich, and the position (longitude) of any point on the sphere may be definitely fixed as "so many degrees east or west of the meridian of Greenwich."

Having now established two reference lines—the equator for latitude and the meridian of Greenwich for longitude—New York (or any other point) may be located on the sphere in much the same way that a point is located with respect to X and Y axes on a plane surface. See figures 15 and 16.

TIME

The earth makes one complete rotation of 360° with respect to the sun in 24 hours. The equator could therefore be divided into 24 hours as logically as into 360°, each hour being equal to 15° of longitude. For some purposes longitude is expressed in hours, minutes, and seconds of time, instead of degrees, minutes, and seconds of arc. From the following table, it is apparent that the longitude of a place may be expressed, for example, either as 75° or as 5 hours west of Greenwich.

Due to the inclination of the earth's axis, the eccentricity of its orbit, and other irregularities, the length of a day is not constant, and the sun is at times ahead of the clock; at other times it is slower. Time

TABLE 2.—*Relation between arc and time*

Time to arc	Arc to time
1 hour = 15°	1° = 4 min.
1 min. = 15′	1′ = 4 sec.
1 sec. = 15″	1″ = 1/15 sec.

measured by the irregular motion of the sun itself is known as "apparent time," or as "true solar time."

For many purposes this variable time is not satisfactory, and it is supposed that a "mean sun" moves uniformly around the heavens. A day is defined as the time required for one complete rotation of the earth with respect to this mean sun. Mean solar time is the time ordinarily kept by our clocks and watches.

Figure 17.—Standard time zones of the United States.

Prior to the adoption of zone time or "standard time" by the railroads in this country in 1883, every city had its own local time, and much confusion naturally resulted. Originally each standard time zone was 15° of longitude (1 hour) in width, with the first zone centered on the meridian of Greenwich. Eventually many irregularities crept in, as communities decided to keep the standard time of some large city farther east or west. War time ("daylight saving time") has introduced further complication, by moving all clocks one hour ahead.

Figure 17 shows a very generalized picture of the four standard time zones of the United States. In any given zone the time is one hour earlier than in the adjacent zone to the east, one hour later than in the zone to the west. Almost the entire surface of the earth is divided into standard time zones, the limits of which are shown on a chart published by the

Hydrographic Office of the U. S. Navy Department (H.O. 5192: Time Zone Chart of the World).

In reporting estimated time of arrival (ETA) to an airway traffic control center, pilots sometimes become confused and add an hour when it should have been subtracted, or vice versa. The best practice is to report according to the watch time actually being kept by the pilot. If his watch is set to central war time, his ETA, for example, should be given as "1730 central war time" (5:30 p. m., see p. 270), leaving no doubt in the mind of either the pilot or the control tower operator concerning the time referred to.

DATE

In these days of global interests and global navigation it is essential to be able to determine the date, as well as the hour, for any place on earth. It is considered that each new day begins at the International Date Line which, in general, coincides with the meridian 180° from Greenwich, in the vast expanse of the Pacific where there are the fewest people to be annoyed by its peculiarities.

In figure 18, the circumference represents the equator, P the pole, PM the International Date Line, PG the meridian of Greenwich. When the sun is over the meridian of Greenwich, it is noon at Greenwich, but midnight on the opposite side of the earth at the date line, where a new day is being born at that moment. Let us call the day Monday. The new-born day "grows" or travels westward around the earth, at the rate of 15° of longitude each hour. Twelve hours later, the new-born Monday reaches the meridian of Greenwich and it is midnight there, while the sun is over the date line where it is now Monday noon.

Monday follows Sunday, of course, and it is as though it were pushing Sunday ahead of it until it reaches the date line again. Sunday is now gone and for an instant Monday has spread over the entire earth; east of the date line it is just beginning, west of that line it is ending. In another moment Tuesday has started on its trip around the world, while Monday retreats before it. Tuesday is found west of the date line, Monday to the east. Thus, the navigator who crosses the date line going from west to east goes from Tuesday into Monday, and must go backward one day on his calendar. Traveling from east to west, he goes from Monday into Tuesday and must add a day.
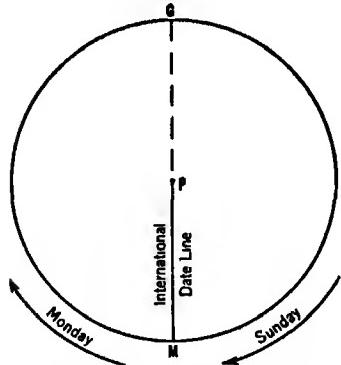
Figure 18.—The birth of a day.

In celestial navigation, and to an increasing degree in other forms of navigation, the time of an observation or fix is always converted to Greenwich time and date. In practice this eliminates a great deal of confusion. If the life-cycle of a day is thoroughly understood, this should never be difficult.

SIDEREAL TIME

With the introduction of the Air Almanac, a knowledge of sidereal time is no longer necessary for any of the standard methods of navigation. There are certain special methods of celestial navigation which offer very real advantages, however, for which some knowledge of sidereal time is essential. Those who expect to have no use for these methods need not be concerned with this section.

Ordinary civil time is based on the rotation of the earth with respect to the sun (strictly speaking, with respect to the *mean* sun), the civil day being the period of time required for one complete rotation. Sidereal time is also based on the rotation of the earth, but a sidereal day is the period required for one complete rotation with respect to the stars.

As illustrated in figure 19, at the same time that the earth rotates on its axis it is also traveling along its orbit around the sun, at the rate of almost a degree a day (360° in approximately 365 days).

Since the nearest star is so much farther away than the sun, there is no appreciable difference in the direction of a star throughout the year, while the direction of the sun changes from day to day. Thus, the solid earth and the sun (fig. 19) are in direct line with a distant star, which we
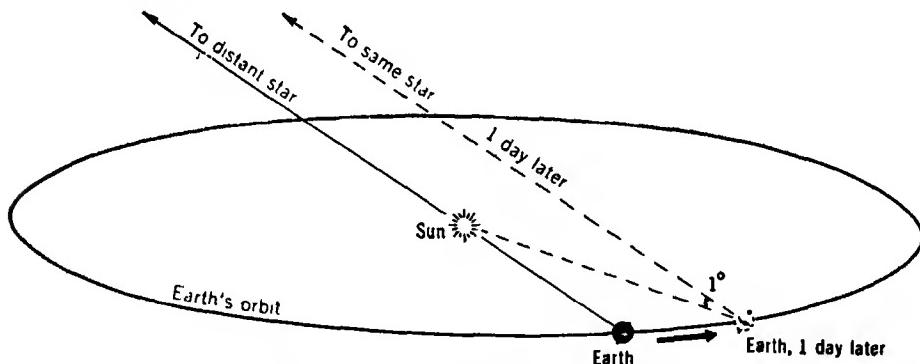
Figure 19.- The civil day and sidereal time.

will suppose is located exactly at the vernal equinox, or first point of Aries. As the point on the earth which is directly opposite (away from) the sun and star begins to rotate, let us consider that the civil day and the sidereal day for that point begin simultaneously. The dotted earth marks its position near the end of the civil day, about 1° farther along in its orbit. It has already completed one rotation with respect to the distant star, but must turn almost another degree to complete one rotation with respect to the sun. It is evident, then, that the civil day is longer than the sidereal day, the difference amounting to about 3 min. 56 sec.

THE SEASONS

If the earth's axis were perpendicular to the plane of its orbit, instead of inclined, summer and winter would cease to exist, and the climate in

any latitude would remain the same the year around. This condition is illustrated in figure 20, where the parallels for each 15° of latitude are shown.

A 15° belt of latitude near the equator would receive the nearly vertical rays of the sun over its entire surface, every cloudless day in the year, as indicated at *A*. A 15° belt near either pole would receive only the heat and light represented by the narrow bands at *B*. To make the discrepancy
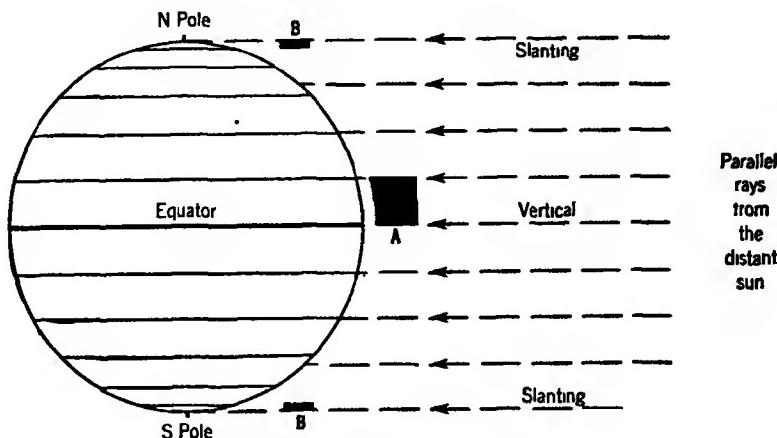
Figure 20   Distribution of sunlight if the earth's axis were vertical.

even greater, a large proportion of the vertical rays of the sun would be absorbed by the earth in equatorial regions, while a large proportion of the slanting rays near the pole would be reflected from the glazed white surface of snow and ice. The days and nights would be equal throughout the year, for any place on earth. At the poles, the sun would be always on the horizon, and continuous daylight would result.

The inclination of the earth's axis introduces summer and winter and other interesting variations. Figure 21 may be considered as an enlargement of the summer and winter portions of figure 14.

With the axis inclined at an angle of about 23½°, in the summer the vertical rays of the sun fall upon the parallel of latitude about 23½° north of the equator, at *A*. This parallel which marks the northern limit of the sun's apparent travel, is known as the Tropic of Cancer. In the winter the sun is directly above the parallel of latitude about 23½° south of the equator, at *B*, this parallel being known as the Tropic of Capricorn.

In the summer, the slanting rays of the sun extend not only to the north pole, as it would if the axis were vertical (see fig. 20), but about 23½° beyond it, to a parallel which is known as the Arctic Circle (fig. 21). Within that circle, in the summer, when the sun is farthest north, the sun does not set, but is visible throughout the 24 hours. At the south pole the sun's rays fall about 23½° short of the pole and, at the same time, do not fall within the Antarctic Circle at all. In the winter, as shown at the right of figure 21, this condition is exactly reversed.

The side of the earth toward the sun (that is, the side toward the center of the figure) is in each case the daylight side. The point *A*, which at noon in summer received the vertical rays of the sun, in the winter is at *A'*, and receives not nearly so much of the sun's light and heat. This is the principal cause of the seasons.

When the earth is about halfway between its summer and winter positions (fall and spring) the sun is directly over the equator, and days
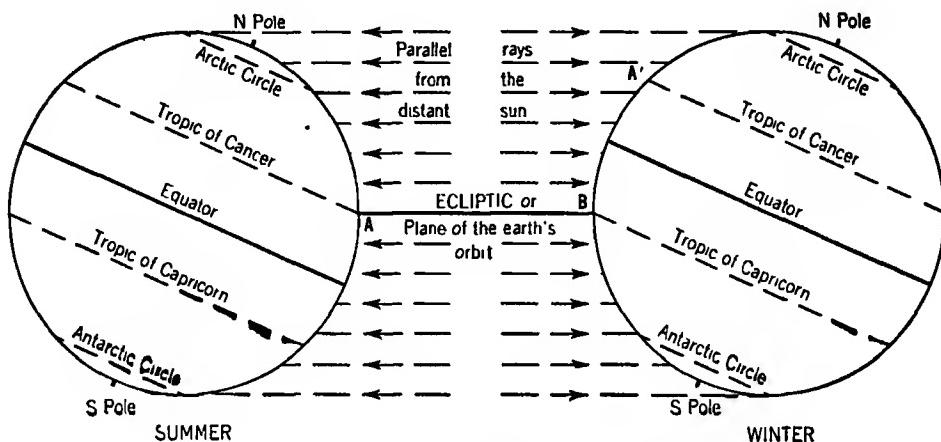
Figure 21.—Explanation of the seasons.

and nights are equal all over the earth. This has resulted in the word "equinox" (equal + night).

CLIMATE

Climate at any place may be considered as the average of all the variable weather conditions at that place over a long period of time. The most important influence, of course, is latitude, which determines the amount of heat received from the sun, but there are a number of other modifying factors.

The influence of mountains on climate has already been mentioned. In the mountains of New Mexico the average winter temperature is as low as at New York, about 500 miles farther north. Again, the break in the Cascade Mountains at the Columbia River, allows the warm air from the Pacific Coast to flow through, and as far east as Idaho causes average temperatures nearly 10° higher than in nearby areas.

On Mt. Mitchell (N. C.) the average annual snowfall of 70 inches is about twice that of Boston, nearly 500 miles further north. The longer retention of snow on the mountains in the spring, in some cases continuing throughout the year, has its effect on temperatures in nearby areas.

Climate is also modified by the presence of large bodies of water, which absorb heat more slowly than land masses, but retain it longer. As a result, water areas are cooler in summer and warmer in winter than the adjacent land areas.

A further important factor is found in the great ocean currents, such as the Gulf Stream. Because of the influence of the Gulf Stream, the climate of Great Britain is much milder than might be expected for an area which lies farther north than any part of the United States. A similar effect is produced on our own west coast by the California Current.

DURATION OF DAYLIGHT

To an observer at any point on the earth, it appears that he stands at the center of a horizontal surface. It is never apparent that the whole plane of his horizon is in any other than a "horizontal" position, nor that he himself is in any other than a "vertical" position, on top of the world.

At the upper left of figure 22 the earth is shown with axis inclined at the proper angle. The horizon of an observer at the equator is shown,
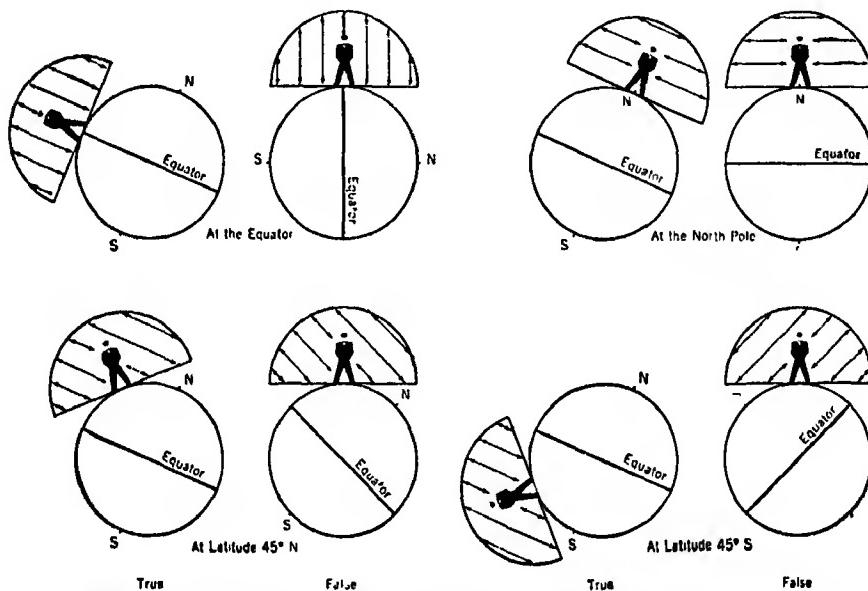
Figure 22.—Horizon at various latitudes compared with false impressions of the "horizontal."

and the apparent direction of motion of the heavenly bodies is indicated by arrows. Second from the left is illustrated the false impression of his relation to the earth entertained by the same observer. At the upper right is shown the corresponding information for an observer at the north pole.

At the lower left of the figure there are shown the true condition and the false impression for an observer at latitude 45° north, and at the lower right the same information for one at 45° south. Note that in each case the apparent motions of the heavenly bodies are along lines parallel to the equator.

The distance from the earth to any of the celestial bodies is so great that the radius of the earth is as nothing by comparison, and it is usually reckoned that the true horizon passes through the center of the earth.

Figure 23 may be considered as an enlargement of the true portions of figure 22, with the true horizon for a selected point drawn through the center of the earth in each case, and with the tropics added.

The length of the Tropic of Cancer from its intersection with the horizon to the circumference just south of Miami represents half the period the sun is above the horizon of Miami at mid-summer. The corresponding distance along the Tropic of Capricorn provides the same information for mid-winter. At Seattle the duration of daylight is much longer in summer, much shorter in winter. At Barrow, above 71° in Alaska, at mid-summer the sun is above the horizon throughout the day, and at mid-winter it is below the horizon all day. At Buenos Aires, duration of daylight is much shorter in June than in December.

Because of the decreasing angle between the horizon and the equator (see fig. 23), the length of summer daylight increases with the latitude. This is demonstrated graphically in the figure; it may be shown much more clearly with a globe, and students should refer to a globe often, not only in studying these matters, but for many of the problems of navigation.

When the sun first sinks below the horizon it does not become dark at once, but "twilight" lasts for the navigator until the sun is 6° below
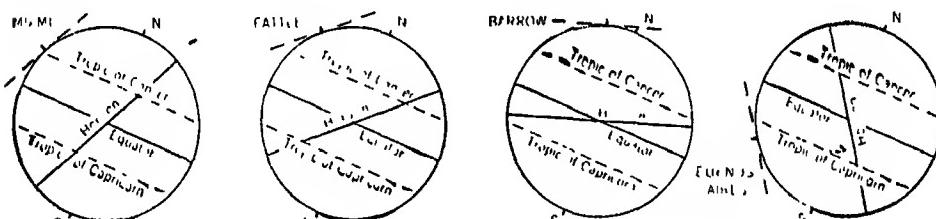
Figure 23   Duration of daylight at Miami, Seattle, Barrow, and Buenos Aires.

the horizon. Astronomers do not consider that twilight has ended until the sun is about 18° below the horizon. Even when the sun has passed below the horizon in a long slant, as for the horizon of Barrow, it may not descend below the twilight zone, or at least is a long time in doing so, and the period of daylight is lengthened accordingly.

WINDS

If the permanent extremes of temperature pictured in figure 20 existed, and the earth were not rotating, the heavier air from the cold polar areas would flow directly toward the equator, as shown in figure 24. The lighter, rising air at the equator would be drawn back toward the poles at higher levels, there to descend and repeat the cycle.

With the same extremes of temperature but a rotating earth, this circulation is modified. In order to understand the modification introduced by rotation, let us follow a particle of air southward, from the north pole toward the equator.

At the equator, a point on the surface of the earth is moving a little more than 1,000 miles an hour (approximately 25,000 miles in 24 hours). Near the pole this surface motion decreases almost to zero. Air near the surface of the earth partakes of the same velocity as the adjacent surface. A particle of air traveling southward from the pole moves into latitudes which are traveling progressively faster toward the east than its own original easterly velocity. It is soon left behind, therefore, by the faster
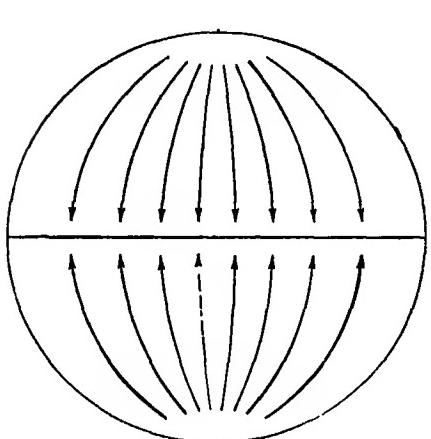
Figure 24.—Wind system of nonrotating sphere with vertical axis.
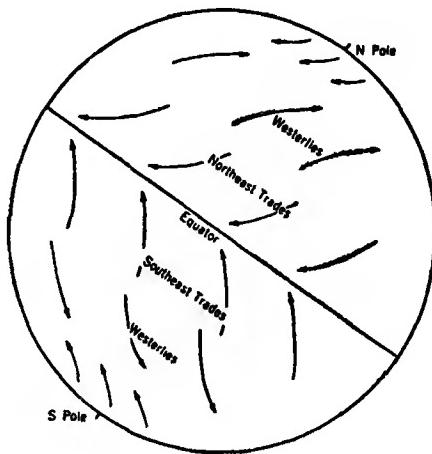
Figure 25.—Generalized picture of principal winds prevailing on the earth.

moving earth, and we say it has been deflected toward the right. In the southern hemisphere this process is reversed, and air is deflected toward the left.

Figure 25 is a greatly generalized picture of the winds actually prevailing on the earth, rotating on its inclined axis. This condition is still further modified in any given locality by the presence of large bodies of water, mountain ranges, and other topographic details.

THE UNITED STATES IN THE MODERN WORLD

German strategy has been based largely on the conception of a "Heartland" in the center of Eurasia, surrounded by the "World Island." According to this idea, whoever ruled the Heartland could command the entire world, and it was in keeping with this belief that the invasion of Russia was begun.

The notion of a "Heartland" was not unreasonable in the days of land power and sea power alone, but in the present air age it is just as reasonable to look upon North America as the new Heartland, or strategic center of the world. Today it is both the arsenal of democracy, and the chief hope of food for a hungry world.

Located between two oceans, it has all the advantages of land power and sea power, and—more important to all the Americas—the commerce of peace. In addition, by way of Alaska or Greenland, air power has

brought us within easy distance of any part of Europe or Asia. See figure 13, or a globe.

With great natural resources, rich farm lands, large rivers, splendid harbors, and rapid transportation, the United States, located in the midst of the Americas, is almost as fortunate and self-sufficient as could be desired. The advantage of a common language and freedom from border disputes with our good neighbors to the north and south have enabled us to concentrate on industrial and cultural development, rather than the strifes that have been so common in Europe. The completion of the Pan-American highway from Alaska through South America, with the increasing benefits of air travel, may be expected to promote an even closer relationship through better understanding.

Modern geographies and atlases include maps showing the bands of sea-borne commerce between the United States and the rest of the world. With a little study of such maps it is easy to understand the strategic importance of Panama, Gibraltar, Suez, or Singapore. It is still hard to predict how much air transportation will modify this picture. Inland towns, far removed from yesterday's sea-borne commerce, tomorrow may become as important as New York or London in the system of air commerce. Desert islands and arctic wastes may become strategic stops along intercontinental air lanes.

In view of the ever larger part the United States must play in world affairs, any time spent in a study of world maps will be well repaid. Study of a good map of the United States is essential. Note on the maps the topography, railroads, harbors, and other factors contributing to the development of great centers such as New York, Chicago, New Orleans, Los Angeles, and Seattle. In the same way, make a study of Archangel, Malta, Buenos Aires, and Sidney.

A SHRINKING EARTH

When George Washington was President it took weeks to travel from Washington to Philadelphia. Three weeks were required for a post rider to carry mail from New York to Boston. Today, either trip can be made by air within an hour or two.

A generation ago it taxed the imagination of Jules Verne to have his hero complete his journey "Around the World in Eighty Days," in the then popular novel of that name. In 1931 Post and Gatty accomplished this by air in a little more than 8½ days. This time was further reduced in 1938 by Howard Hughes to 3 days, 19 hrs., 14 min.

Prior to the war, the month or more required for a surface crossing of the Pacific had been reduced to a week by commercial airliners. Today, airplanes of the Army's Air Transport Command have delivered strategic cargo across the Atlantic and returned to their base for another load in less than two days. One commercial airplane has crossed the Atlantic twice in one 24-hour period. Numerous magazine articles call attention to the fact that "no spot on earth is more than 60 hours from your local

airport." Truly, we live on a shrinking earth. For many purposes its dimensions should no longer be given in miles, but in time.

The immediate implications of our shrinking earth are military. No longer can people in any part of the world feel safe because enemies are at great distances from them, as they are separated by only a matter of hours. In the years that follow, it is hoped that the easier interchange of ideas, and the closer contacts with other peoples will promote a better understanding and lead to an enduring peace.

QUESTIONS

1. What is the earth's principal source of light and heat?

2. What is the earth's average distance from the sun? Is it closer to the sun in summer, or in winter?

3. What is earth's greatest height? Greatest ocean depth?

4. What percent of the earth's surface is land?

5. Define the following geographic terms: island; continent; isthmus; strait; peninsula.

6. What evidence of early glaciation may be found in the United States?

7. How do mountains affect climate?

8. Are regions near large bodies of water likely to have extreme changes in temperature, or less-than-average changes?

9. What reasons can you give in support of belief that the earth is round?

10. How is the slight flattening of the earth taken into account in navigation?

11. What is meant by the inclination of the earth's axis?

12. How does the inclination of the axis affect the seasons? Climate?

13. Why are winds deflected to the right in the northern hemisphere, and to the left in the southern hemisphere?

14. By what coordinates is a point located on the surface of the earth?

15. With respect to what reference line is latitude measured? Longitude?

16. In what terms is latitude measured? Is longitude always measured in the same terms.

17. How is the difference of latitude obtained between two points in north latitude? Two points in south latitude? A point in north latitude and a point in south latitude?

18. How is the difference of longitude obtained between two points in west longitude? Two points in east longitude? A point in west longitude and a point in east longitude?

19. What is the difference of longitude between a point in 170° east longitude and a point in 170° west longitude? ·

20. What is the approximate length, in statute miles, of a degree of latitude near the equator? Near latitude 60°? Near latitude 90°?

21. What is the approximate length, in statute miles, of a degree of.longitude at the equator? At latitude 60°? At latitude 90°? (NOTE: A table giving these and other related values is included in U.S.C.&G.S. Special Publication No. 5: Tables for a Polyconic Projection of Maps.)

22. State the relationship between longitude and time.

23. How is the length of a day determined? Of a year?

24. Is a sidereal day longer or shorter than the ordinary civil day?

25. When it is noon at Washington, D. C., what time is it at Los Angeles? At Greenwich? At the international date line?

26. Name the four standard time zones of the United States.

27. In crossing the international date line from east to west, should a pilot add or subtract a day?

28. What determines the following circles on the earth: Tropic of Cancer; Tropic of Capricorn; Arctic Circle; Antarctic Circle?

29. What is meant by the word "equinox"?

30. At what season of the year are the days and nights equal?

31. What part of North America lies in the same latitude as the British Isles? Are the British Isles warmer or colder than the corresponding latitude in North America? Why?

32. Is the day longer at Barrow, Alaska; at the Panama Canal; or at Buenos Aires—(a) in the middle of June; (b) in the middle of December?

33. How would you define the word "horizontal"?

Chapter III.—CHART PROJECTIONS FOR AIR NAVIGATION

THE ROUND EARTH ON A FLAT CHART

No considerable part of the surface of a sphere can be spread out in a plane without some stretching or tearing. In attempting to flatten out a portion of a hollow rubber ball, as under glass, the outer part must be stretched or torn before the central part can be pressed into the same plane with it.

If only a small portion of the earth's surface is to be shown, it may be represented on a plane surface with negligible distortion. When a large number of such maps have been made, it will be found that they cannot be joined together so as to lie flat. If they are carefully joined along the edges it will be found that they naturally adapt themselves to the shape of the globe.

While it is impossible to represent a sphere upon a plane accurately, there are some surfaces that can be spread out in a plane without any stretching or tearing. Such surfaces are called developable surfaces; those like the sphere are called nondevelopable. The cone and the cylinder are two well known surfaces that are developable.

If a paper cone is cut in a straight line from base to apex (fig. 26), the surface of the cone can be spread out in a plane with no stretching or

a. Cone cut from base to apex.

b Development of the cone's surface
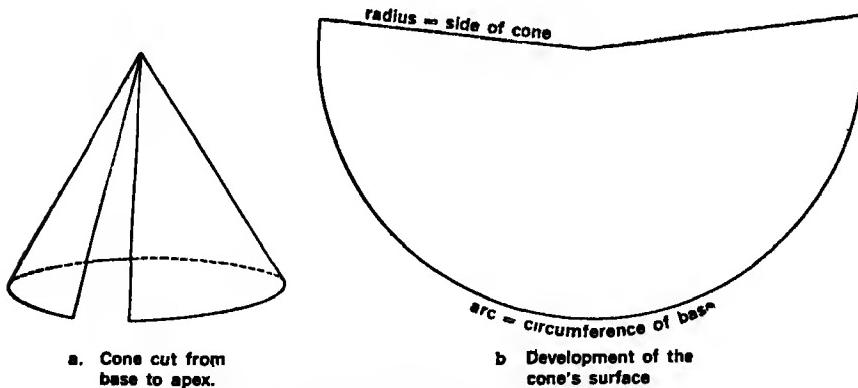
Figure 26.—Development of a conical surface.

tearing. Any curve drawn on the surface will have exactly the same length after development that it had before.

In the same way, if a cylindrical surface is cut from base to base the whole surface can be rolled out in a plane. See figure 27. In this case, also, there is no stretching or tearing of any part of the surface.

Since the sphere cannot be directly developed into a plane surface, it is customary first to project the reference lines of the sphere upon some developable surface, as a cone or cylinder. This is done by mathematical analysis, but the process may be visualized by supposing a tiny light at the center of a transparent sphere, projecting a shadow network of

meridians and parallels upon a tangent cone or cylinder (fig. 30). When this developable surface has been unrolled into a plane, we have a more or less satisfactory representation of the reference lines of the sphere

<div style="text-align:center">circumference of base of cylinder</div>

a   Cylinder cut from
     base to base

b   Development of the
     cylinder's surface
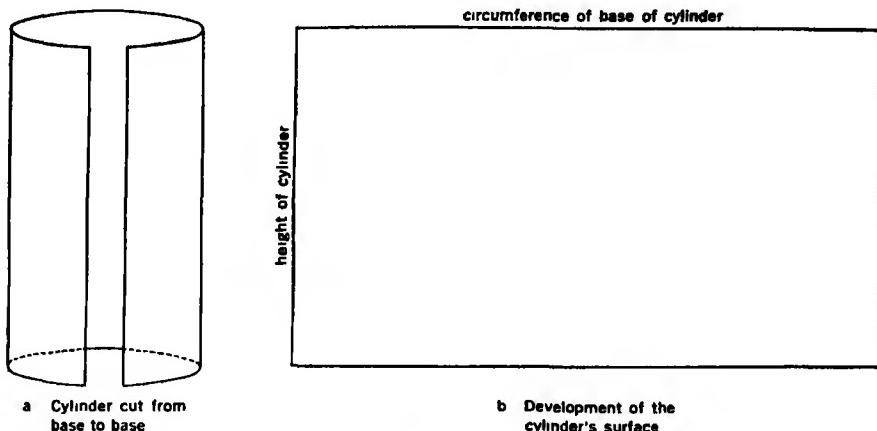
Figure 27 —Development of a cylindrical surface.

upon a plane surface. The system of lines representing the meridians and parallels of the sphere is known as a chart projection. It is the foundation upon which the chart or map is built.

PROPERTIES OBTAINABLE IN A PROJECTION

A great many systems of projection have been devised, each intended to serve some particular purpose, or to preserve some special property of the sphere. One text, Petermann's Mitteilungen, Ergansungsband 48, 1935, tabulates and classifies as many as 237 projections. Some of the properties which it would be desirable to preserve in a chart are:

1. The true shapes of physical features, including correct angular relationships;

2. Equal areas, or the representation of areas in their correct relative proportions; and

3. True scale values, for measuring distances.

Other properties often desired and obtained are:

4. The representation of great circles as straight lines;

5. The representation of rhumb lines (see p. 39) as straight lines; and

6. A compromise between several desirable properties, sacrificing a little of one in order to obtain a little more of some other, yet without too much violence to either.

It is possible to obtain any one of these properties, sometimes more than one, in one flat map. It is possible to obtain ALL of them in one map only on a globe. It is necessary, then, to consider what purpose the chart is to fulfill, and to select the projection that most nearly affords the properties desired. The two fundamental problems of all forms of

navigation are distance and direction. Special consideration will be given, therefore, to these two items on the sphere, and to their representation in the projections studied.

DISTANCE ON A SPHERE

In plane geometry a straight line is defined as "the shortest line that can be drawn between two points." It is on this principle that a carpenter stretches a chalked line between two points and snaps it lightly against the floor to obtain, in a faint chalk impression, a straight line.

On the surface of a sphere, the shortest distance between two points lies along the arc of a great circle. This does not mean, of course, that the shortest distance is not along the most direct route, for a great circle may be popularly defined as "the straight line of the sphere." This is illustrated in figure 28 where a string is stretched over the globe, from New York to London, to obtain the great circle route (shortest distance)
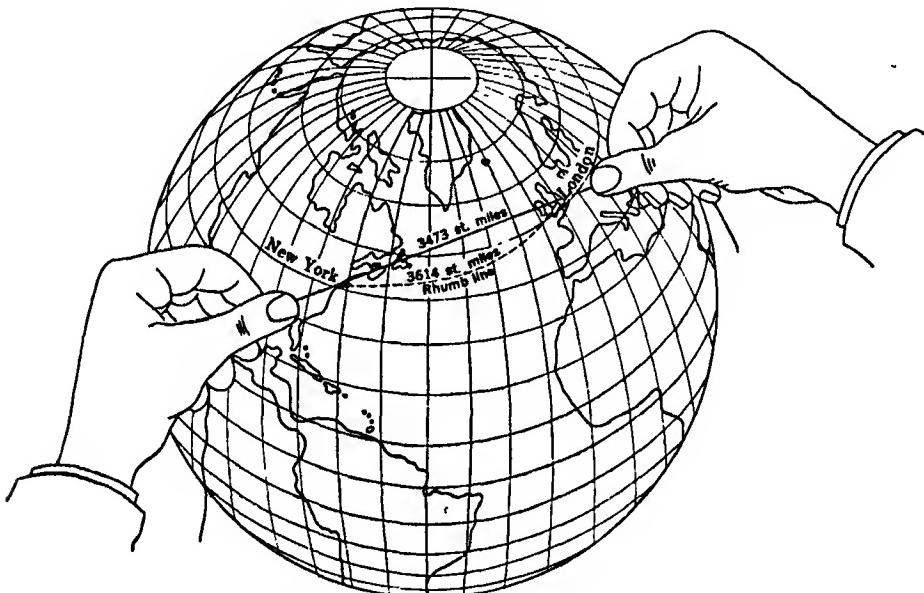
Figure 28.—Great circle versus rhumb line

between the two points. A great circle is so called because it is one of the family of largest circles that can be drawn on a sphere.

More exactly, a great circle on the earth is a line marked out by the intersection with its surface of any plane passing through the center of the earth. Stated another way, all circles upon the earth which divide it into two equal parts are called great circles. The equator is a great circle, and so are all meridians. The plane of a great circle, of course, may be at any angle to the plane of the equator or to the earth's axis. Figure 29 illustrates these definitions.

From the definition of a parallel of latitude, it is clear that a parallel divides the sphere into two unequal parts. A parallel is therefore not a

great circle, but a small circle. Any circle, the plane of which does not pass through the center of a sphere is known as a "small circle," regardless of its size.

Distance along a great circle is measured in the same way that latitude and longitude are measured along the great circles represented by the meridians and the equator—that is, in degrees, minutes, and seconds of arc. For most purposes, the distance is then converted into the ordinary distance units of nautical miles, statute miles, or kilometers. For all practical purposes, a minute of latitude, or a minute of any other great circle, may be considered as a nautical mile. Because of the flattening of the earth near the poles, the length of a minute of latitude varies somewhat, increasing with the latitude, from the equator to the poles. In the

The equator is a great circle

Any meridian is a great circle

C = center of the earth

A parallel is NOT a great circle

Any plane passing through the center of the earth cuts the surface in a great circle
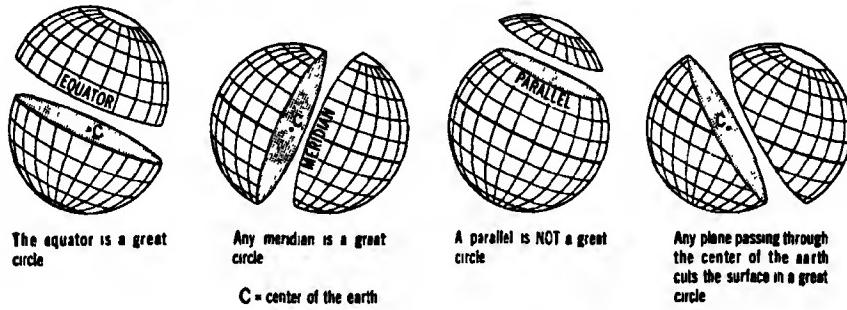
Figure 29.—Grea   arth.

United States, however, the length of a nautical mile is definitely fixed at 6,080.20 feet. A "knot" is the unit of speed in nautical miles per hour. For example, a speed of 120 nautical miles per hour should be expressed as "120 knots."

The statute mile is more commonly used on land, and also for air navigation, although nautical miles are used by the Navy. The graphic scales printed on the various series of aeronautical charts are all based on the statute mile of 5,280 feet. A scale of nautical miles is provided by the meridians, which are graduated in minutes of latitude.

DIRECTION ON A SPHERE

There are two kinds of direction on a sphere—great-circle directions and rhumb-line directions. Great-circle directions are illustrated in figure 28, from which it is seen that the string makes an angle of about 50° at the meridian of New York, about 90° with the meridian of Iceland, and a still greater angle with the meridian of London. In other words, the direction of the great circle is constantly changing as we progress along the route, and is different at every point along the great circle. Great-circle directions, then, always refer to the direction at a particular point: for example, the great-circle bearing of London *from New York,* or from St. Johns, or from a point on the meridian of Iceland.

A rhumb line may be defined as a line which crosses all meridians of the earth at a constant angle. A ship or an airplane that holds to a

constant course is making good a rhumb line over the surface of the earth. From figure 28 it may be seen that the rhumb line between New York and London crosses all meridians at an angle of about 80°.

As already pointed out, a great circle represents the shortest route between two points; the rhumb line is somewhat circuitous, and is always longer. Note that in this case the great circle route from New York to London is 141 statute miles shorter than the rhumb line. For distances of less than 1,000 miles the saving in distance by way of the great circle usually is not great enough to be of practical importance.

THE LAMBERT PROJECTION

This projection is properly known as the Lambert conformal conic projection. For the sake of brevity it is commonly referred to as "the Lambert," since it is the best known projection bearing that name. To avoid any confusion, when referring to other projections devised by Lambert the full name should always be given: for example, the "Lambert equal area projection."

This projection was introduced in 1772, but was little known until, during the first World War, it was adopted by the Allies for their military maps because it afforded maximum accuracy of directions and distances. Since these are the two basic problems of all navigation, when the Coast and Geodetic Survey was assigned the task of preparing charts for air navigation the Lambert projection was given serious consideration. It was selected, however, only after a thorough investigation had indicated that it afforded a very desirable combination of properties and advantages. Two properties, both of which are vital in air navigation, are the speed and accuracy with which navigational problems may be solved.

The Lambert projection is not obtained graphically, by geometrical projection, but is derived from rigid mathematical formulas to afford the property of conformality. By this term it is meant that true shapes of limited areas and true angular relationships are retained (property 1, p. 37). In Europe the term "orthomorphic" is used for a projection of this nature. In view of the foregoing, figure 30 must not be looked upon as illustrating the actual derivation of the projection; rather, it is a picture of its general form and properties.

The meridians and parallels of the earth are projected upon a cone which intersects the surface of the earth along two standard parallels. The standard parallels on the earth and on the cone coincide, and along them the scale is therefore exact. Between the standard parallels the earth is projected *inward* upon the cone, and the scale of the cone is somewhat smaller than the scale of the larger earth. Outside the standard parallels the earth's surface is projected *outward*, and the scale of the cone is slightly larger than that of the earth.

The standard parallels of true scale adopted for all aeronautical charts of the United States are latitudes 33° and 45°. Figure 31 shows a portion of the developed Lambert cone, with the outline of the United States. Note that the meridians of the earth are represented by straight lines
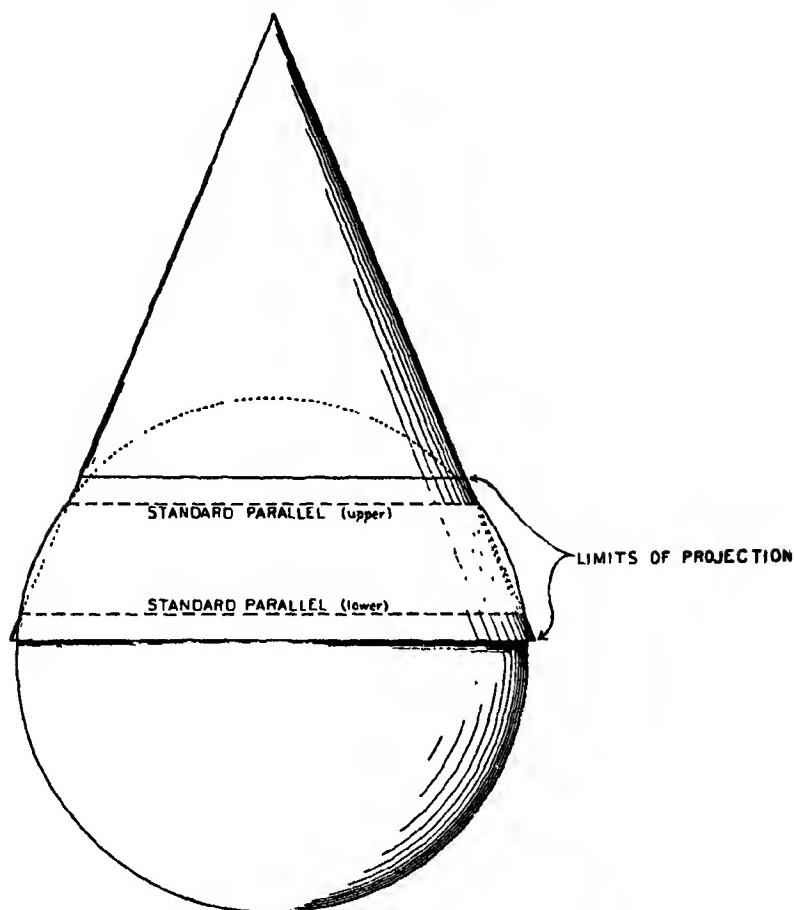
Figure 30.—The Lambert conformal conic projection.

49° (101 $\frac{1}{25}$ %)

45° (Scale exact)

39° (99 $\frac{9}{20}$ %)

33° (Scale exact)

25° (102 $\frac{1}{3}$ %)

Scale error about $\frac{1}{2}$ of 1%
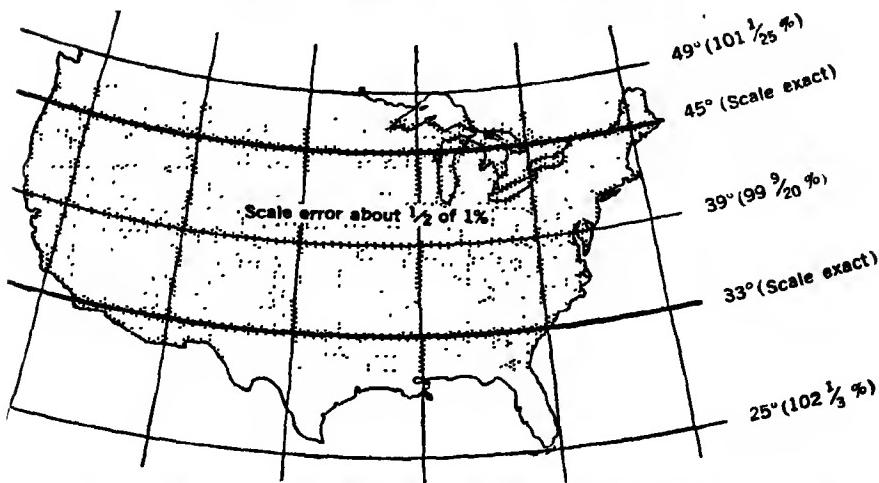
Figure 31.—A portion of the developed cone, Lambert conformal conic projection, showing scale properties.

converging toward a common point (the apex of the cone) outside the borders of the chart. They may be considered as radii of the parallels, which are represented by arcs of concentric circles. The common center of the parallels, of course, is at the point of intersection of the meridians. Meridians and parallels intersect at right angles, and the angles formed by any two lines on the earth's surface are correctly represented.

The excellent scale properties of the projection are also illustrated in figure 31, where it is seen that for about 90 percent of the area of the United States the maximum error is about one-half of 1 percent—that is, one-half mile for every 100 miles. The scale error of any single chart is so small that distances may be measured as if the scale of the chart were constant.

Prior to the war, the Alaskan aeronautical charts were largely completed, using standard parallels of 55° and 65°. For the Philippine charts, tables had been prepared using latitudes 7° and 20° as standard parallels. When the necessities of war demanded aeronautical charts of the world in minimum time, it was realized that, by merely inverting these projections for south latitudes, the three Lambert projection bands already available provided satisfactory tables for almost the entire world. All that was needed to complete the system was a stereographic table for the polar areas. Figure 32 shows the resulting series of projections used for the planning charts of the world (scale 1:5,000,000). For the world
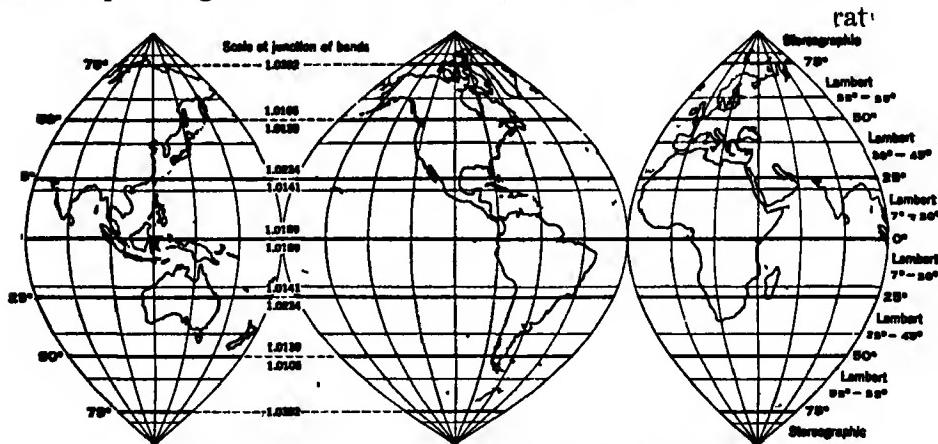
Figure 32.—Projection scheme for aeronautical charts of the world.

series of charts at scale 1:1,000,000, this arrangement was slightly modified, as shown in figure 33. In the frontispiece, at the right, these projection bands have been assembled to show how nearly they approximate a sphere.

In each projection band, essentially the same small variations in scale illustrated in figure 31 are present. These excellent scale properties are invaluable in any method of navigation; they are of increasing importance in view of the reasonable certainty that positions may soon be fixed by determining distances from radio stations in much the same way that directions are now measured, from signals received.

For certain special charts of areas near the junctions between bands, other Lambert projections have been constructed, using the standard parallels best suited to the area under consideration. Those now available (1945) are included in the table on page 47.
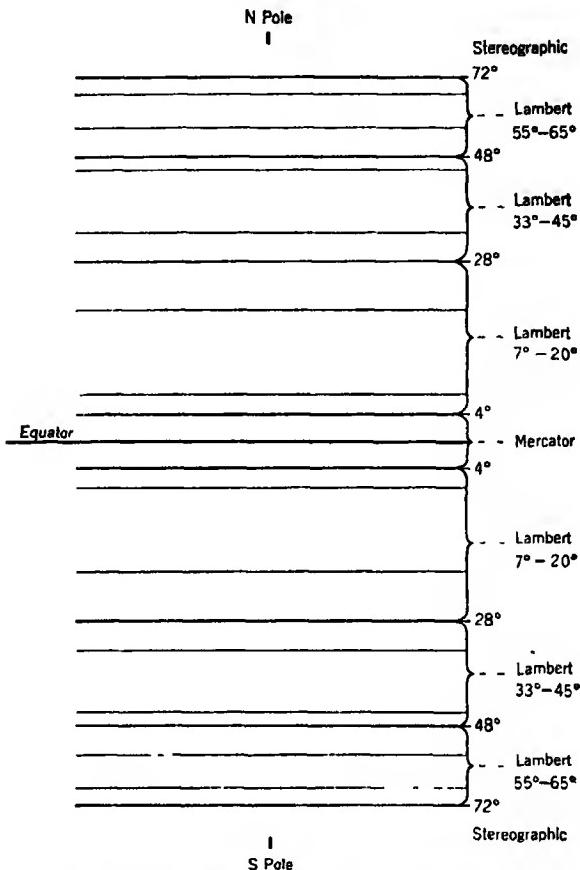
Figure 33.—Projection bands for world aeronautical charts, scale 1:1,000,000.

In order to plot a great-circle route on this projection, a gnomonic chart is usually not required. A straight line on the Lambert chart is a close approximation to the path of a great circle, and for all practical purposes may be regarded as the shortest route between two points. For example, through the central part of the planning chart of the United States on the Lambert projection a straight line so closely approximates a great circle that for all practical purposes it may be so considered. The same is true for a line between low latitudes and high latitudes, however great the distance (for example, from Miami to Seattle; see fig. 34). For a long line east and west, along the Canadian border or across the Gulf (as Miami to Brownsville), the straight line on the Lambert departs appreciably from the line representing the true great circle. Even in these areas, the distance represented by the straight line differs very little from

the true great-circle distance. It should be remembered, however, that a
straight line on the Lambert only *approximates* the path of a great circle;
for any purpose in which the precise great circle track is of interest,
a gnomonic chart such as C.&G.S. chart No. 3074a should be used.
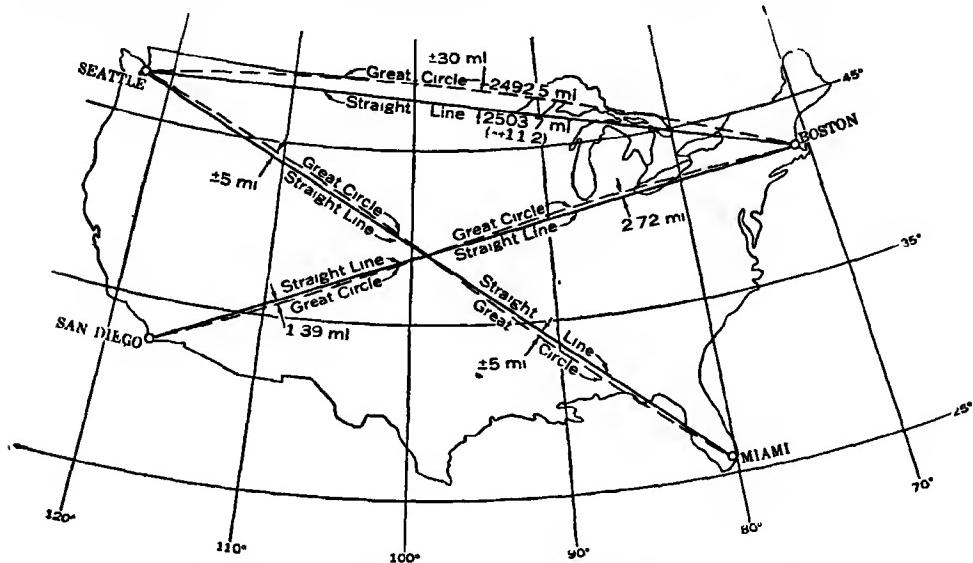
Figure 34.—Straight lines on the Lambert are approximately great circles.

Great-circle directions and rhumb-line directions can be obtained with
equal ease from the Lambert projection. In air navigation, great-circle
directions are usually referred to as *bearings* or *azimuths;* a rhumb-line
direction is known as a *course.* The measurement of both courses and bear-
ings is illustrated in figure 35.
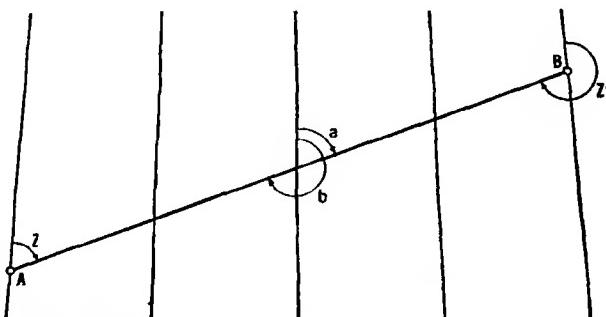
Angle a is the course to be followed from A to B,
Angle b is the course to be followed from B to A,
Angle Z is the bearing, or azimuth, of B as measured at the point A,
Angle Z' is the bearing, or azimuth, of A as measured at the point B;

Figure 35.—Courses and bearings.

Since a bearing is a great-circle direction, it must be referred to some
particular point, and is therefore always measured at the meridian passing

through that point; a course is always measured at the meridian nearest halfway between the two points in question.[1]

Courses and bearings are both measured clockwise from the north, from 0° up to 360°.

A bearing is constantly changing as we progress along the route and is different at every point along the great circle (except for the special cases in which the two points are both on the same meridian, or are both on the equator); a course is the average of the changing directions of the great circle, and may be followed without change for the entire distance between the two points (if, for the moment, we disregard magnetic variation, compass deviation, and wind).

The course from A to B is the exact reciprocal of the course from B to A (that is, exactly 180° different); the bearing of A from B is never the exact reciprocal of the bearing of B from A, but differs therefrom by an amount equal to the angular convergence between the meridians through the two places.

Courses are used continually in all problems of dead reckoning; the use of bearings (azimuths) is confined to radio navigation and celestial navigation almost exclusively.

The terms "bearing" and "azimuth," as used in air navigation, are identical, but the former term is generally used in radio navigation, the latter in celestial navigation.

It should be explained that when the course is measured with the meridian nearest halfway (as the angle a, fig. 35), an airplane following that course will not exactly follow the straight line AB (great circle) on the chart, but will slightly depart from it near the middle of the route, as indicated by the light, broken line (rhumb line, greatly exaggerated) in figure 36. When courses are measured as recommended on page 105,
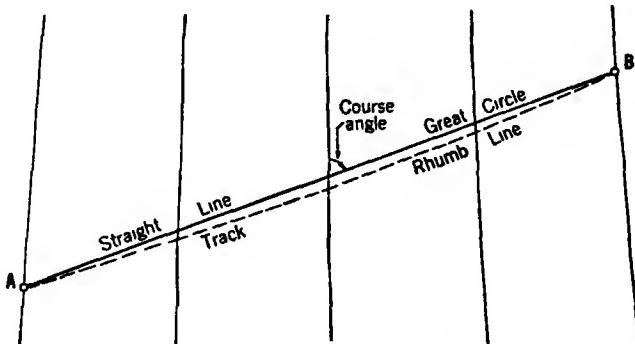
Figure 36.—Course and track.

however, the departure is so slight that it may be considered that the airplane does exactly track the straight line throughout its entire length.

[1] For theoretical precision, long courses should be measured with the meridian of middle longitude between the two points, rather than the meridian nearest halfway. This applies only to very long distances, however, and is an unwarranted refinement, the maximum course error from this cause being too small for practical consideration in the United States.

Figures 35 and 36 illustrate the measurement of courses and bearings on charts of the northern hemisphere. For charts in the southern hemisphere the procedure is identical, as shown in figure 37. Meridians in this case converge toward the south pole, but all courses and bearings are measured with reference to true north, as already discussed.
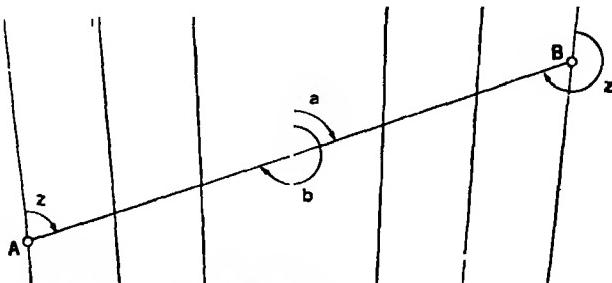
Angle a is the course to be followed from A to B.
Angle b is the course to be followed from B to A.
Angle z is the bearing, or azimuth, of B as measured at the point A.
Angle z' is the bearing or azimuth of A as measured at the point B.

Figure 37 —Courses and bearings in the southern hemisphere.

These properties of the Lambert projection provide for very simple methods of air navigation. They are developed more completely in later chapters, but are briefly summarized here. It may be said of the projection, for charts within any Lambert projection band, that:

1. It permits a perfect junction between any number of charts in any direction.

2. It is unexcelled for scaling distances in all directions.

3. Its directions conform very closely to directions on the earth, and it is therefore unsurpassed for all types of radio navigation.

4. It affords a simple and satisfactory solution for all problems of dead reckoning, not excepting the rhumb line.

5. It provides the simplest possible method of practical great-circle navigation.

6. It is well suited to all problems requiring the plotting of positions, and for celestial navigation.

When charts of one projection band are to be matched with those of another band, perfect junctions cannot be obtained. In this case, charts can only be joined by rolling contact, often referred to as a "rolling fit." See figure 38. An appreciable overlap on each of the planning charts serves to minimize this condition, which illustrates the first sentence in this chapter, "No considerable part of a sphere can be spread out in a plane without some stretching or tearing." In the system of projections for world charts, the stretching and tearing has been kept to a minimum.

In some of the problems of air navigation the convergence of the meridians is of interest. The following table gives the convergence per degree of longitude for each of the projection bands now available (1945);

that is, the angle on the chart between two meridians a degree apart is the fraction of a degree indicated. The angle between two meridians five degrees apart is equal to five times the fraction tabulated. For most
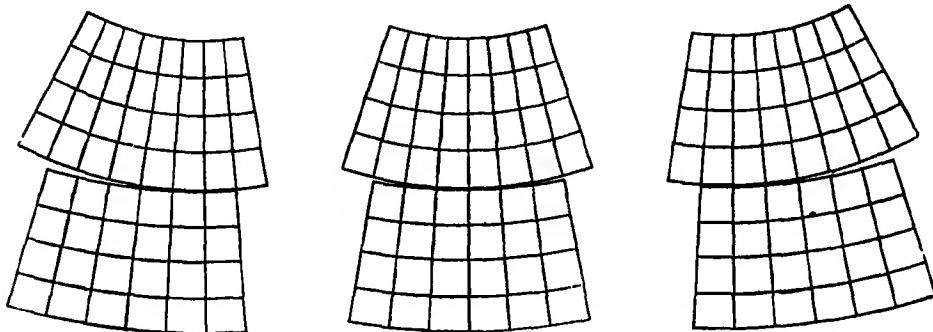
Figure 38.—Rolling contact between charts in adjacent Lambert projection bands.

practical purposes values to the nearest tenth of a degree are sufficiently accurate.

TABLE 3.—*Convergence of meridians per degree of longitude, for various Lambert projection bands*

General extent in latitude	Standard parallels	Convergence
0° – 25°	7° and 20°	0°234
25 – 50	33 and 45	.631
50 – 75	55 and 65	.867
10 – 45	17 and 33	.424
35 – 70	45 and 58	.784
0 – 90	30 and 75	.817

THE MERCATOR PROJECTION

This projection was introduced by Gerhard Krämer, better known as Mercator, in 1569—now nearly 400 years ago. Today it is used almost exclusively for the nautical charts of the world.

In air navigation it is used by naval pilots in order to provide uniform methods and procedure for both the air arm and surface vessels. It is used by the Army Air Forces for their series of long-range navigation charts (scale 1:3,000,000 on the central parallel of each chart); for a few special charts (at scale 1:1,000,000); and for a series of outline charts for use with the astrograph in celestial navigation (scale 1:1,000,000 at latitude 56° north).

The Mercator projection may be described as a special case of the Lambert, in which the apex of the cone has receded to infinity and the cone has become a cylinder. Like the Lambert, it is derived from rigid mathematical formulas in order to obtain the property of conformality, and cannot be obtained by geometrical projection. Its meridians and parallels are represented by two sets of parallel lines at right angles to

each other. Figure 39 shows a map of the world on the Mercator projection.

On the earth itself, the meridians converge toward the poles. On this projection the meridians do not converge but, on any given chart, are everywhere the same distance apart. This means that as we approach the poles the meridians of the projection are too far apart. In order to compensate for this, and to retain true angular relationships, the parallels of latitude are also spaced at proportionately greater intervals, so that the shape of each rectangle of the projection is kept proportional to the shape of the same rectangle on the earth.

Since both meridians and parallels on this projection are spaced too far apart in areas appreciably removed from the equator, it is clear that those areas are distorted and are shown too large with reference to the areas near the equator; that is, the scale of the more distant parts is larger.
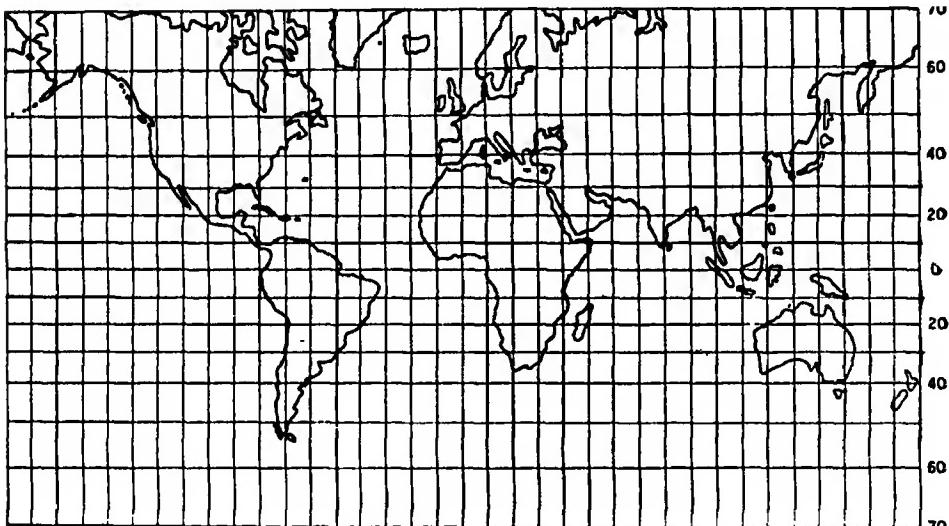
Figure 39   Mercator projection of the world.

The change of scale from the most southerly part of the United States to the most northerly point amounts to about 40 percent. That is, if we adopt a scale of 80 miles to the inch at the southernmost part of a chart of the United States, the scale at the northernmost part of the chart will be 48 miles to the inch. If the central parallel of a chart of the United States is chosen for a true scale of 80 miles to the inch, then the scale at the southern part is a little more than 91 miles to the inch (about 14 percent too small), and at the northern part about 63 miles to the inch (about 21 percent too large). A comparison of the Mercator variation in scale with the total variation of each Lambert projection band is given in figure 40. The frontispiece (center) shows a Mercator "globe" made up of Mercator bands having the same limits as the Lambert projection bands. At the left the entire world, exclusive of the polar areas, is shown

on a single Mercator band. The stereographic projection should still be used for the polar areas, as with the Lambert system.

Because of the distortion of areas and the rapidly changing scale, for many general purposes the Mercator projection is not suitable. It was designed, not merely to provide another conformal projection, of which there were many, but to provide a projection on which all rhumb lines would be represented as straight lines. This was a distinct advantage in the days of slow surface vessels when a constant course might be followed for a full day, and the day's run could be plotted as a single straight line. In air navigation, however, because of changing magnetic variation (see p. 112) and changing winds, the swifter aircraft seldom hold to one heading more than an hour. The track over the ground must therefore be plotted on the smaller scale aeronautical charts as a series of short lines,
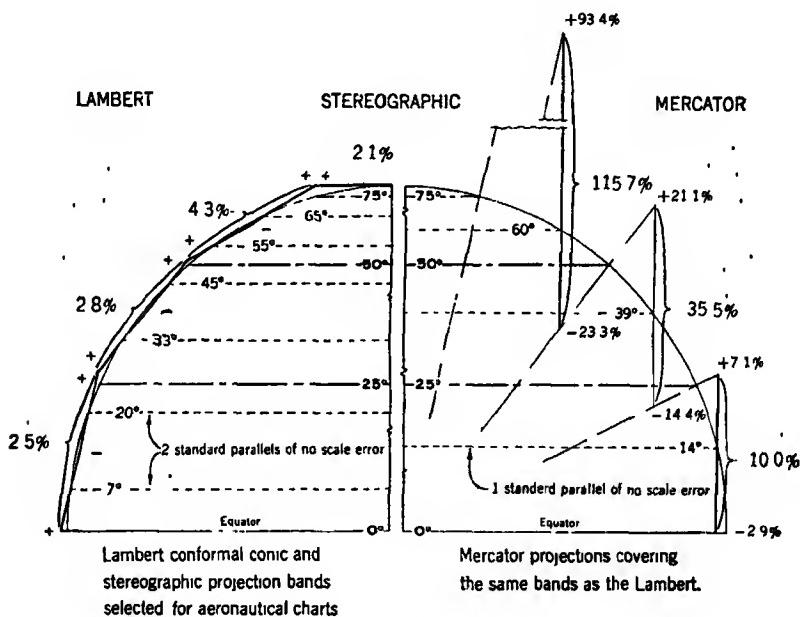
Figure 49. Variation in scale of each projection band.

and the one important advantage of the rhumb line disappears. In recent years it has even been suggested that the Lambert projection might advantageously replace the Mercator for use at sea, particularly in higher latitudes.

On a Mercator chart the condition illustrated in figure 28 is exactly reversed: the sphere has been distorted so that the rhumb line is straight, and the great circle has become a curved line above it. On this projection all great circles are represented by curves concave toward the equator, and they therefore appear to be longer than a rhumb line. This is not actually true, of course, but is a deception of the projection; in short, a straight line *on this projection* does not represent the shortest distance between two points.

If it is desired to follow a great circle, the route must first be **drawn**
on a great-circle chart (gnomonic projection) on which all great **circles**
appear as straight lines. A number of points along the route drawn on
the great-circle chart are then transferred to the Mercator chart, by
latitude and longitude, and a smooth curve is drawn through the points.
The curved line on the Mercator is next broken down into a number of
sections of convenient length, and the rhumb-line course for each section
is followed. In this way the great-circle route is approximated by a
series of rhumb-line courses.

Due to the variation in scale, a simple graphic scale of miles such
as is used on the Lambert cannot be used satisfactorily for measuring
distances, even for a single Mercator chart. Instead, a scale diagram
showing the scale of miles at each latitude is used, or distances are
measured in terms of nautical miles (minutes of latitude) by reference
to the subdivided meridians or the subdivided border scales commonly
running north and south along the east or west margin of such a chart.
In any case, the portion of the scale used must be the scale for the mean
latitude between the two points in question.

Figure 41 illustrates the ordinary method of measuring distance
on a Mercator chart. A unit of 60′ (or any convenient unit) near the
center of the route is taken from a subdivided meridian and stepped off
from A toward B. In this case the 60′ unit is stepped off twice, with
some left over. The portion left over is then set on the dividers and when
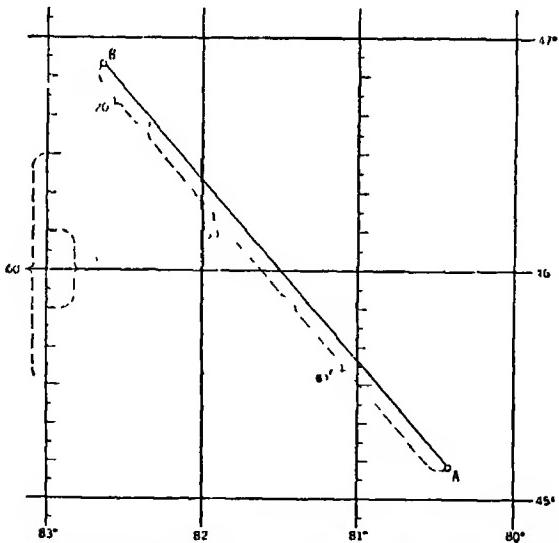
Figure 41.—Measuring distance on a Mercator chart.

applied to the subdivided meridian, near the center of the route, is found
to equal 20′. The total distance, then, is 60 + 60 + 20 = 140 minutes, or
nautical miles. If the distance is desired in statute miles, this may be
obtained by multiplying the number of nautical miles by 1.15. Since

measurements of distance are necessarily frequent in air navigation, this method seems rather involved.

Strangely enough, when great-circle distances are measured in this way on a Mercator chart, the apparently longer line representing the great circle is found to be shorter than the straight rhumb line, as it should be. The explanation, of course, is that the great circle is always in higher latitudes than the corresponding rhumb line; the unit selected for measuring the great-circle distance is also in higher latitudes and therefore longer, and goes into the great-circle distance fewer times.

Rhumb-line directions (the only directions commonly used in dead reckoning) are most easily determined from a Mercator chart, since the course angle may be measured at *any* meridian, instead of the meridian nearest halfway, as with the Lambert.

Great-circle directions are used in radio navigation, since radio signals follow the paths of great circles. That is, a radio bearing reaches the navigator using a Mercator chart by way of the curved line representing the great circle between his position and the transmitting station (fig. 42). If he wishes to plot the bearing as a straight line he must apply
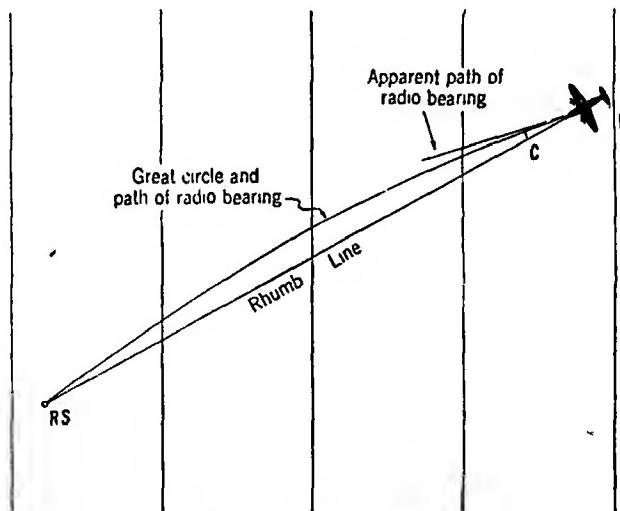
Figure 42.—Radio bearings on a Mercator chart.

a correction equal to the difference between the final direction of the great circle and the direction of the straight rhumb line (angle *C*). This correction, given in table 5, p. 228, for various latitudes and differences of longitude, is sometimes to be added, sometimes subtracted, depending on whether the airplane is east or west of the transmitting station, and north or south of the equator. This correction is generally unnecessary with the Lambert.

Because of the variation of scale, it is the usual practice to draw each Mercator chart true to scale at the central parallel of each chart. When this is done, adjacent charts to the east or west may be joined

perfectly; charts to the north or south (or charts in adjacent projection bands) may be joined only by sliding contact (see fig. 43).

By way of final comparison, the Lambert has a constant distance scale but courses must be measured at the meridian of middle longitude:
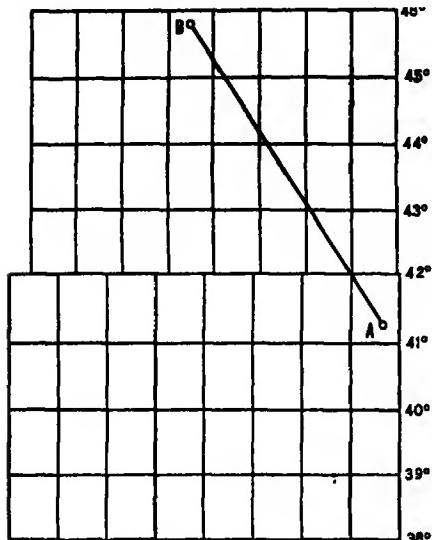
Figure 43.—Sliding contact between adjacent Mercator charts to the north or south.
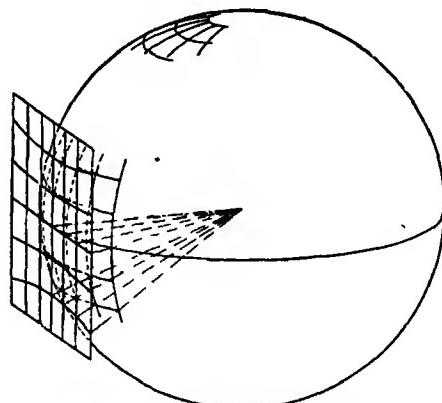
Figure 44.—The gnomonic projection.

the Mercator has a constant course angle, but distances must be measured (usually in nautical miles) at the scale of the middle latitude, and great circles can be found only by transfer from a gnomonic chart.

THE GNOMONIC PROJECTION

This is probably the most ancient of all map projections, and has been credited to the Greek philosopher, Thales, 550 B. C. It is believed that it was developed by the ancients in their effort to project the stars of their night sky, which appeared to them as if fixed on the inner surface of a great sphere, upon an imaginary plane beyond it. At any rate, the projection is obtained by projecting the meridians and parallels of the earth upon a tangent plane, the point of projection being at the center of the sphere. See figure 44.

The definition of any great circle requires that its plane pass through the center of the earth. It therefore follows that from this central point all great circles would be seen as straight lines and would be so projected on the tangent plane. This, in fact, is the one desirable property of the projection. Distortion of distance and direction increases rapidly as the distance from the center of the projection (the "point of tangency") increases. On maps or charts covering any great extent, shapes become almost unrecognizable. It is impossible to show as much as a hemisphere on this projection, since points 180° apart would be projected to infinity.

Since all meridians are great circles, they always appear on the

gnomonic projection as straight lines. They will be parallel straight lines when the point of tangency is at the equator, converging when the point of tangency is elsewhere, the convergency increasing as the point of tangency approaches the pole. Parallels of latitude appear as curved lines.

From the center of the projection all bearings are true. At any other point, error is present, and a distorted compass rose (protractor) must be constructed, or other special methods resorted to, for the measurement of direction. This has been done in a few cases, for certain radio direction finding charts, with a special compass rose constructed around each radio direction finding station.

Charts on the gnomonic projection are used chiefly as an adjunct to Mercator charts, as the easiest means of finding the track of a great circle for transfer to the Mercator chart. Small scale gnomonic charts of the ocean areas have been published by the Hydrographic Office of the U. S. Navy Department. As far as is known, U. S. Coast and Geodetic Survey chart No. 3074a, "Great-Circle Chart of the United States," is the only chart on this projection covering any appreciable extent of the earth's land surface.

THE STEREOGRAPHIC PROJECTION

This projection is only slightly less ancient than the gnomonic, being credited to Hipparchus, in the second century before Christ. As with the gnomonic, the earth is projected upon a tangent plane, but in this case the point of projection is the opposite end of the diameter of the earth from the point of tangency (see fig. 45). Because of this, an entire hemisphere, or even more, can be charted on a single stereographic projection.
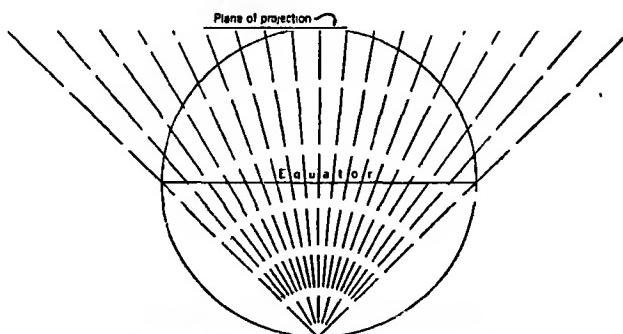
Figure 45.—The stereographic projection.

When the stereographic projection is centered at the pole, all meridians are straight lines radiating from the center, and parallels of latitude are concentric circles about the pole.

As with the Lambert and Mercator projections, figure 45 must be considered only as a picture of the general nature of the stereographic projection. It is a conformal projection, and is derived from the same

general formula as the Lambert. It is, in fact, another special case of the Lambert, the apex of the cone in this instance having been brought down into the plane of projection.

Being conformal, it has the same properties as the Lambert projection and is susceptible to the same methods of navigation. It was therefore chosen for aeronautical charts of the polar areas. In figure 45 the plane is shown tangent at the pole. Without changing the nature of the projection in any way, the plane could be brought down until it intersects the sphere. The parallel of latitude along which it intersects in this case becomes a "standard parallel" of true scale. For the 1:1,000,000 series of Air Force charts the projection was constructed so as to match the scale of the adjacent Lambert charts along latitude 72°; this results in a standard parallel for this series at about latitude 83°25'.

For aeronautical charts the use of the stereographic projection is limited to the polar areas. The point of tangency may be at any other point from the equator to the poles, and the projection is often so used for general purpose maps.

PROJECTIONS FOR WEATHER CHARTS

Many special problems are met in meteorological work, and special projections are required for easy plotting and interpretation. There are only a few of these, however, with which the navigator will need to be familiar, and most of them represent only slight modifications of projections that have already been discussed.

For weather charts centered on equatorial regions, the ordinary Mercator projection is used. Each of these charts extends from latitude 45° south to 45° north. At the extreme latitudes of these charts the scale is approximately 40 percent larger than at the equator; however, there are large overlaps with charts on other projections to the north or south, and the extreme latitudes are little used except for general reference. Also, the item of distance is of less importance in meteorological work than in the plotting of navigation problems.

Extending from equatorial regions to the north pole there is a series of weather charts on a Lambert conformal projection with standard parallels at latitudes 30° and 75°. With the standard parallels so widely spaced, and with such broad extent in latitude, the excellent scale properties obtained for the Lambert aeronautical charts cannot be expected. Nevertheless, for the broad central regions of chief interest in this series (latitudes 20° to latitude 80°) the maximum variation from the scale of the standard parallels is less than 8 percent (minus 7.87 percent to plus 7.85) the total variation in scale being not quite 16 percent. If precise distances are required for any reason, they may be obtained by means of a diagrammatic scale, printed in the margin of the chart and giving the correct graphic scale at any desired latitude.

The north and south polar areas are each covered by a single chart on the stereographic projection, centered on the pole and extending to middle latitudes.

A south latitude series of weather charts on the Mercator equal area projection provides broad overlaps with the equatorial charts on the ordinary Mercator projection and the south polar stereographic chart. This projection is also known as the sinusoidal (because the meridians are sine curves), and sometimes as the "Sanson-Flamsteed projection," after two later map-makers who made use of it.

In the Mercator equal area projection, all parallels of latitude are shown by parallel straight lines. Only the central meridian is straight, and all other meridians are curved, being concave toward the central meridian. Distances between all parallels of latitude (along the central meridian of the projection) are true, and distances along each parallel are true. Figure 46 shows the general appearance of the projection for one of these charts. It is apparent by inspection, that distances in other
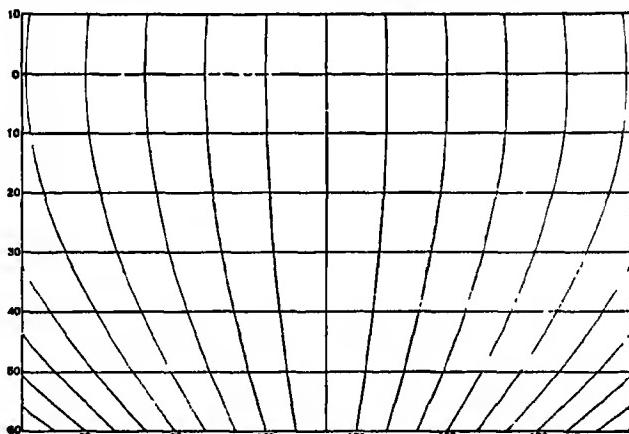
Figure 46.--Mercator equal area projection, used for some weather charts.

directions are distorted; nevertheless, for measurements not far removed from the central meridian the distortion is negligible. As the name implies, the area represented by a square inch anywhere on the chart is equal to the area represented by a square inch in any other part of the chart.

Other charts for climatological studies have also been prepared on this projection, with the polar areas shown on the Lambert equal area projection, but navigators are not likely to find use for these charts.

QUESTIONS

1. What is meant by a "developable" or "non-developable" surface?
2. Why are cones, cylinders, and other similar figures used as an intermediate step in chart projections?
3. Name as many as possible of the properties of a sphere that might be obtained in various chart projections.
4. In what projection may all the properties of the sphere be retained?

5. What is meant by a compromise, or conventional projection?

6. What are the two fundamental factors of navigation?

7. Define a great circle; a rhumb line; course; bearing; azimuth; parallel of latitude; meridian.

8. Is the distance between Chicago and Moscow greater by way of the great circle or rhumb line?

9. Define a nautical mile.

10. Name some of the principal great circles on the earth, and some reference lines that are not great circles.

11. Is a parallel of latitude a rhumb line.

12. In what projection are the meridians straight lines and the parallels arcs of circles?

13. What is meant by a "conformal" projection? An "orthomorphic" projection?

14. The ordinary Mercator projection is a conformal projection. Would you say that the shape of North America is correctly represented on it?

15. State the family relationship between the Lambert, Mercator, and stereographic projections.

16. What is meant by a standard parallel?

17. Approximately how many degrees of latitude are included in each Lambert projection band?

18. What is the approximate total variation in scale in any given Lambert projection band? on a single Lambert chart?

19. Could the polar areas be charted on an ordinary Mercator projection?

20. Explain the methods of plotting a great-circle route on a Mercator chart, on a Lambert chart, and on a stereographic chart.

21. Name the only projection on which all great circles are exactly represented by straight lines.

22. Describe the method of measuring courses and bearings on a Lambert chart; on a Mercator chart.

23. How is distance measured on a Mercator chart?

24. What is meant by "rolling contact" or "sliding contact" between charts?

25. If the scale is held true on the central parallel of each Mercator chart, how many charts to the north or south can be joined before resorting to a "sliding contact"?

26. If the age of a projection determined its value, which projection would be "best" (oldest) ?

27. On the earth, meridians converge toward the poles; on the Mercator projection they do not. How is this compensated for in the projection?

28. On a Mercator chart does a straight line represent the shortest distance between two points?

29. How great must the distance be before the difference in the length of a rhumb line and the great circle becomes appreciable?

30. What is the principal navigational use that is made of a gnomonic chart?

31. Is the gnomonic a conformal projection? How can you prove your answer?

32. Name one additional projection used for some weather charts.

33. How does the Mercator equal area projection differ from the ordinary, or conformal Mercator?

Chapter IV.—INSTRUMENTS

THE FUNCTION OF NAVIGATIONAL INSTRUMENTS

The pilot of a modern transport airplane faces an array of something like 100 different instruments and gadgets. The great majority of these have nothing to do with navigation; some, such as fuel gages, oil temperature gages, and manifold pressure gages, furnish information with regard to the functioning of each engine; other instruments, such as aileron-tab controls, and the flaps-position indicator, have to do with the mechanical handling of the aircraft; there are also switches for landing lights, running lights, cabin lights, and for numerous other purposes.

The primary function of the navigational instruments is to furnish continuous indications of distance and direction. This is not quite as simple as it sounds, however, since distance is the product of speed and time, and speed is both horizontal and vertical. The indications of distance and direction must be plotted from some known position in order to determine successive positions of the aircraft; therefore, any instrument which provides an independent determination of position serves not only as a check on previous navigation but also as a new starting point for the continued plotting of distance and direction.

It is not expected that pilots should know the mechanical details of construction, nor that they should attempt their own aircraft-instrument repairs. It is desirable, however, that they should be familiar with the underlying principles of each instrument, in order that they may know its limitations, and what corrections (if any) must be applied to its indications while in flight. There are a number of interesting instruments in process of development, and some of the standard ones appear in various forms. This chapter will be limited to a discussion of the instruments most likely to be used in standard methods of navigation.

THE CLOCK

The clock or watch is included here, since time plays an important part in many of the steps of navigation. For example, fuel consumption is reckoned in time, rather than miles, and a knowledge of elapsed time is necessary in order to determine the distance flown. Also, progress along the charted route is often plotted directly in units of time, when the ground speed is accurately known.

For all ordinary navigation, any good timekeeper is quite satisfactory, and it is unnecessary to obtain clocks or chronometers of elaborate or expensive design. A dollar watch, set to 12 o'clock at the time of take-off, will indicate the elapsed time quite satisfactorily. For many purposes, however, a clock with sweep-second hand that indicates both the time of day and the elapsed time in flight is a convenience.

THE AIR SPEED INDICATOR

As already stated, distance is equal to the product of time and speed. The principal means of determining speed in an aircraft is the air speed indicator. This is a pressure instrument, indicating the pressure resulting from flight through the air in terms of air speed at sea level and at standard atmospheric pressure. A common type of air speed indicator is shown in figure 47.

By "standard atmospheric pressure" it is assumed that the temperature at sea level is 59° F. (15° C.) and that it decreases with altitude at the uniform rate of 3°6 F. (2° C.) for each 1,000 feet. Under these conditions the atmospheric pressure at sea level is equal to that of 29.92 inches of mercury, decreasing with altitude at the rate established for the "standard atmosphere" (see Civil Aeronautics Bulletin No. 25, "Meteorology for Pilots").

Since its indications are based on pressure, the indicated air speed is too low at the reduced pressure found at higher altitudes, even under standard atmospheric conditions. In addition, the temperature and pressure often differ from this arbitrary standard, and a correction determined by the pressure altitude and the temperature actually existing at

Figure 47.—Air speed indicator.

the time and place must be applied. Tables and graphs are available for this purpose, although an air navigation computer is more conveniently used.

In the absence of other means of determining the correction, it amounts to about 2 percent of the indicated air speed for each 1,000 feet above sea level. The true air speed is always greater than the indicated air speed, except for extremely low temperatures at low altitudes. For example, suppose the temperature at 10,000 feet is 0° F., and the indicated air speed is 180 mph. The correction to the indicated air speed is 2% of $180 \times 10(000) = 3.6 \times 10 = 36$ mph. The true air speed then is $180 + 36 = 216$ mph. By computer the true air speed under these conditions is 204 mph, showing that the 2 percent rule is only approximate.

The readings of the air speed indicator should be checked, or calibrated, by a series of timed flights over a measured course on the ground when there is no wind blowing or when the wind's effect on the speed of the aircraft is accurately known. A correction card should then be made up showing the calibrated air speed for any indicated air speed.

If it is merely assumed that the indicated air speed is correct, the dead reckoning position of the airplane may soon become greatly in error. In the example just given, if 180 mph is accepted as the true air speed and there is a wind of 30 mph 135° from the heading of the aircraft, 7° must be applied to correct for drift, and a ground speed of 200 mph will

be indicated. If the true air speed of 204 mph is used, the allowance for wind is only 6°, and a ground speed of 224 mph is determined, a difference of 24 miles in the distance made good each hour. With lower cruising speeds the percentage of error under the same conditions is even greater.

It is important to realize that, while the air speed indicator is in error at any appreciable altitude, its indications are still a trustworthy guide to safe flying speed, regardless of altitude. For example, if the stalling speed of an airplane is 40 miles an hour at sea level, the same pressure, and hence the same indicated air speed, will be necessary to keep it from stalling at any higher altitude.

The air speed indicator also affords information regarding departures from level flights. If the throttle remains unchanged and the air speed increases, it is notice that the nose has dropped and the airplane is in a dive; if the air speed falls off, the nose has come up and the airplane is in a climb.

The air speed indicator may be graduated either in statute miles per hour or in knots. A knot is a unit of speed, representing a velocity of 1 nautical mile per hour. It is incorrect, therefore, to speak of an air speed of "100 knots per hour"; it is only necessary to say, "100 knots."

THE RATE OF CLIMB INDICATOR

The speed of an aircraft is both horizontal and vertical, and this instrument is often known as a "vertical speed indicator." It is generally similar in principle to the air speed indicator but is calibrated to indicate the rate of change of altitude in feet per minute.

Unlike the air speed indicator, it is compensated for altitude and temperature, and the indicated readings may be accepted without correction. The rate of climb indicator is usually found only on transport planes, or on other aircraft intended to be used in instrument flying and for instrument approach procedures. Figure 48 shows a typical rate of climb indicator.

THE ALTIMETER

This is simply an aneroid barometer, registering atmospheric pressure on a scale calibrated in terms of altitude instead of inches of mercury. It consists of a small, airtight chamber, from which most of the air has been removed. The pressure, or weight of the outside air tends to collapse the chamber, but this tendency is resisted by a spring. As the atmospheric pressure increases, the chamber is compressed; as it decreases, it is again expanded by the spring. This slight motion is magnified mechanically, and registered in terms of the altitude that would produce a corresponding change in pressure under standard conditions.

Figure 49 shows an altimeter of conventional type. The small hand registers thousands, and the large hand hundreds of feet of altitude. The altitude indicated in the figure is 4,080 feet. At one side of the dial there is a barometric scale which can be set to correspond to the barometric pressure existing at the time in the vicinity of the flight. In the figure

this scale is set for a pressure of 29.95 inches of mercury. The altimeter setting may be obtained from the latest available hourly teletype sequence weather report before taking off; it should also be continually changed during flight, to conform to the setting for the nearest ground station. It is broadcast as the "altimeter setting," and is given in inches of mercury; it should not be confused with the barometric pressure, which is reported in millibars. When the current altimeter setting for a particular airport has been applied, the instrument will indicate very closely the field elevation above sea level when the wheels of the airplane touch the ground.

When temperatures and pressures differ from those of the standard atmosphere, the indicated altitude is in error, and must be corrected. The error amounts to approximately 2 percent of the indicated altitude for each 10° F. (5°5 C.) that the temperature differs from the standard temperature for that altitude. It may be found more easily from a good computer, by setting the existing temperature against the "pressure altitude," which is the altitude above sea level indicated when the barometric scale is set to the standard sea level pressure of 29.92 inches.

Figure 48.—Rate of climb indicator.
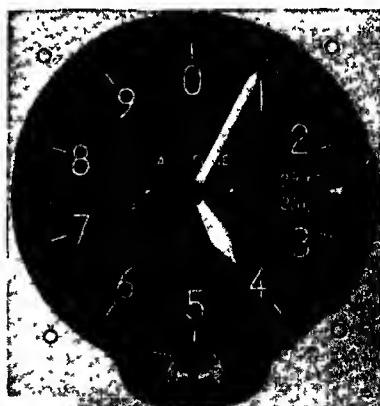
Figure 49.—Altimeter.

If the existing temperature is higher than standard the true altitude is higher than the indicated; if the temperature is lower than standard, the true altitude is lower. The explanation is, that at higher temperatures the air has expanded and is lighter than standard per unit volume; the *change of pressure* per thousand feet will therefore be less, and the altimeter will not read 1,000 feet until the aircraft is higher than 1,000 feet. When the air is colder than standard, it is heavier, and the opposite condition is true.

When the 2 percent rule is followed, the correction is to be added to the indicated altitude for higher-than-standard temperatures, substracted for lower.

It is more dangerous, of course, when lower-than-standard temperatures are found, because the airplane is lower than the indicated altitude.

When temperatures are very low the true altitude may be as much as 20 percent lower than the indicated altitude. Under these conditions the altimeter registers 8,000 feet when the altitude of the airplane is only 6,400 feet—and in mountainous country this could prove disastrous. Extremely low temperatures would be required to produce an error of this magnitude, but normal departures from standard temperatures can result in errors of several hundred feet.

For rather similar reasons the true altitude is lower than that indicated by the altimeter when flying from an area of high barometric pressure into a low pressure area. The same is true, of course, if the pressure falls during flight, before the airplane returns to the point of departure.

The altimeter may be subject to "lag," under certain conditions, and is subject to mechanical errors resulting from corrosion, excessive vibration, or friction. To guard against such errors, it should be calibrated from time to time.

By way of summary, various "kinds" of altitude are obtained from the altimeter, and it is important to understand their derivation and use. All have been referred to in the preceding discussion:

Indicated altitude is the altitude shown on the face of the instrument when set for the barometric pressure ("altimeter setting") actually existing at the time and place of flight.

It is used in making an instrument approach, since, when the aircraft's altimeter is set to agree with the altimeter of the field approached, it will indicate the true altitude of the field after the aircraft has landed. It is also used by all pilots in instrument flight along the airways; while it is not the *true* altitude, it is the same for all airplanes in a given area, and thus provides for safe vertical separation.

Pressure altitude is the altitude indicated with the barometric scale set to the standard sea level pressure of 29.92 inches. It is used on the various air navigation computers in determining the true air speed, and in determining the true altitude.

True altitude is the pressure altitude corrected for temperature. It is used to insure safe clearance of high mountains, and for any other purpose in which knowledge of the true altitude is important. See Chapter VIII.

Reference is also made occasionally to "absolute altitude," and to "density altitude." The former refers to the height of an aircraft above the ground (NOT above sea level); the latter does not pertain to navigation.

THE DRIFT SIGHT

The air speed recorded by the air speed indicator may be quite different from the speed made good over the ground. For example, with an air speed of 120 mph and a head wind of 30 mph, the speed over the ground would be reduced to 90 mph. With a tail wind of the same velocity the ground speed would be increased to 150 mph. The effect on ground speed of wind from either side of the aircraft is dependent upon the

direction and velocity of the wind with respect to the direction and velocity of flight.

Unfortunately, there is as yet no instrument for the direct measurement of wind direction and velocity while in flight. All that can be determined (when visibility permits) is the drift angle. When the drift angles are known on two or more headings approximately at right angles, the wind direction and velocity and their effect on the motion of the aircraft can be determined, as described later.

The greater the air speed, the less is the effect of wind upon the motion of an aircraft; nevertheless, the necessity for accurate navigation on military missions has led to the requirement that wind force and direction be determined by the double-drift method at least every half hour. This is all the more necessary since wind varies with time, place, and altitude, and may differ greatly from the wind predicted.

Fairly elaborate drift sights are used by the Army and Navy, some with auxiliary devices for the determination of ground speed. For accurate results, important corrections and detailed instructions are necessary, for which complete information is available with the instruments.

For commercial and private aircraft a simple drift sight of the type illustrated in figure 50 is entirely satisfactory. The drift sight is installed in an opening in the floor, making sure that the line of zero drift is lined up with the longitudinal axis of the airplane. In flight, the grid ring is rotated until the grid wires are lined up with the apparent motion of the ground. The drift angle may then be read from the grid ring.

The wind correction angle is seldom equal to the drift angle observed; however, if the airplane is headed along the desired track as though there were no wind, the observed drift angle may be applied as an approximate correction. The drift angle on this new heading should then be observed; if it is greater or less than the correction

Figure 50.—Drift sight (floor type).

already applied, the correction should be increased or decreased accordingly. After two or three trials a heading is found such that the total correction is equal to the drift angle observed on the final heading. When this is the case, the proper correction for wind has been made, and the airplane will follow the intended track.

Until recently the scale markings on drift sights have not been uniformly designated. Some have been marked (+) and (—), others have used these same signs, but with the significance reversed, depending upon whether the drift *error* or the drift *correction* was in mind. Still others have used the words "right" and "left," the former indicating that the aircraft is drifting to the right due to a wind from the left, the latter indicating the reverse. This usage ("right" and "left") has finally been accepted as standard.

A very simple and satisfactory drift sight may be made by drawing drift lines on a piece of glass or transparent plastic, as illustrated in figure 51. This drift sight, also, is to be installed in the floor of the airplane, and the drift angle is determined by noting the drift grid line along which the surface of the ground appears to move.

Drift sights have not come into general use in commercial and private aircraft for several reasons. Not the least of these is that, in bad weather, when drift corrections are most important, often the ground cannot be seen and the air is too turbulent to obtain satisfactory drift observations. Nevertheless, it is desirable to learn to use a drift indicator; whenever it can be used it makes accurate navigation possible, and in an emergency it may prove invaluable.

THE MAGNETIC COMPASS

This is the primary instrument for indicating the direction of flight, except in areas near the magnetic poles. It is designed to indicate mag-
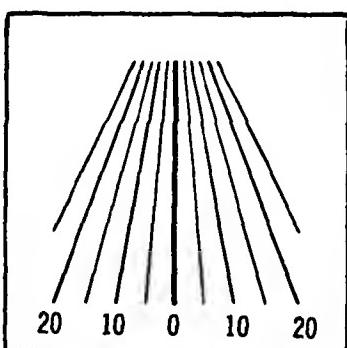
Figure 51.—A simple drift sight (floor type).
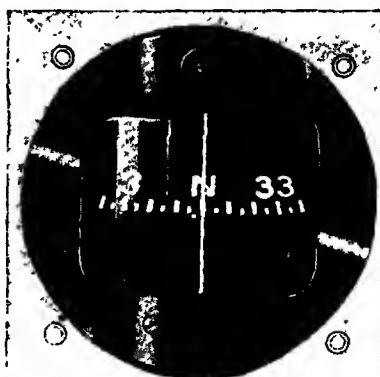
Figure 52.—Magnetic compass.

netic directions by utilizing the directive force of the earth's magnetic field.

The earth may be considered as a large magnet, with two magnetic poles at some little distance from the geographic poles. Along the magnetic equator (that is, about halfway between the magnetic poles) the lines of force of the earth's magnetic field are parallel to the surface of the earth. As the distance from the equator increases, the lines of force become more and more inclined until, at the magnetic poles, they are vertical. The inclined lines of force may be considered as made up of a horizontal component and a vertical component.

The ordinary magnetic compass takes its directive force from the horizontal component of the earth's magnetic field. As long as the airplane is kept horizontal, in straight and level flight, the compass is fairly stable and reliable; with any appreciable degree of bank, particularly on northerly or southerly headings, the compass card is affected by the vertical component, and no longer indicates directions correctly. When the airplane is turned, or is subject to rough air or other abnormal con-

ditions, the compass may even indicate a turn in the opposite direction, and may turn completely around before taking up the correct direction again.

The compass appears in a variety of forms, figure 52 illustrating a common aircraft compass. A clear understanding of the relation between the points of the compass, the 360-degree system of directions, and the indications of the compass itself, is essential. This relationship is illustrated in figure 53.

At the left of the figure is a compass card of the ordinary pocket compass type. Like the aircraft compass itself, it is divided into 360°, the final zero of each number being omitted; thus, 9 represents 90°, 18 represents 180°, and so on. Around the outer edge the cardinal and inter-cardinal points have been indicated in the ordinary terms: north, north-east, east, and so forth.

At the center of the same compass card a tiny airplane is pivoted, like a grasshopper on a pin. As the airplane turns on its pivot it is headed successively in the direction of the various points of the compass. If it is first headed toward the north (expressed either as 000° or as 360°) and
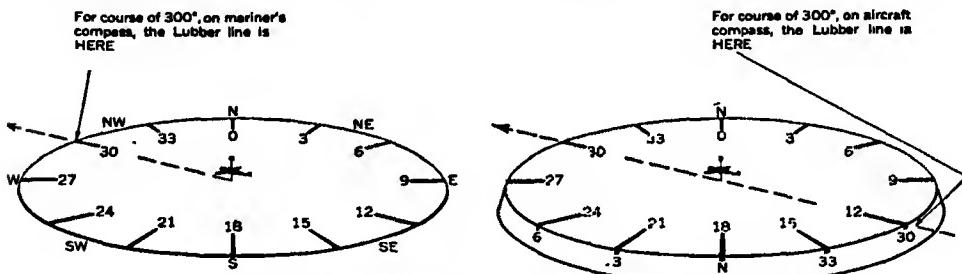
Figure 53.—Common compass card and aircraft compass card.

then turned toward the east, its heading is, successively, changed to 030°, 045° (northeast), 060°, 090° (east), 120°, and so on. In the illustration its heading is 300°. All directions in air navigation are reckoned in this way, as though the pilot were at the center of an ordinary compass card ("compass rose"), looking out over the nose of his airplane to read the direction.

For convenient installation and reading, the aircraft compass is usually installed so that only the edge of the card is visible. Since the directions are to be read from the near edge of the card (see fig. 53, right), and the lubber line (index mark, against which the compass is read) is at the same side of the card, the markings seem to be reversed.

The directive force of the magnetic compass is rather weak, but it may help if we consider that it is so great that the card remains fixed and immovable, with the north part of the card always toward the north magnetic pole; that the pivot of the compass card is also the vertical axis of the aircraft, about which it turns; and that the pilot in his seat moves around the edge of the card, and reads from the edge of the card the directions he would read from an ordinary card if he were at the center looking out over the nose of his airplane.

During construction the iron and steel parts of the airplane acquire a certain amount of magnetism. The ignition system and other electric circuits also may be surrounded by magnetic fields when in operation. These factors affect the compass so that the card does not indicate the magnetic directions correctly on most headings. This error is known as the deviation of the compass. It is different, of course, for each compass installation, for each airplane, and for different headings of the same airplane. It is for this reason that, for a 90° turn, the difference in headings is usually more or less than 90°. For example, if for magnetic north the compass reads 358°, and for magnetic east 92°, the change of heading required to effect this 90° turn is 94°.

The compass direction may be in error on any particular heading, but the error on that heading remains the same, except for changes in the aircraft's magnetism with the passage of time or from severe landing shocks. Deviation is also subject to change from place to place, especially where any considerable difference of latitude is involved. It is particularly likely to be affected by severe electrical storms, and should be checked at least several times a year—certainly before beginning any important flight. The important thing is to know the amount of deviation on the various headings, and to allow for it in navigation (see p. 116). This is accomplished by first compensating the compass, to make the deviation as small as possible; and then "swinging ship," to determine the deviation on headings for at least every 30°. On large airplanes, this is now usually accomplished in flight, using an astro compass (fig. 62) to compare the true direction of the sun at a given instant with its compass direction at the same time.

After this has been done, a deviation card similar to figure 54 is prepared, and fastened near the compass to which it applies. Some prefer

FOR	MH	N	30	60	E	120	150
STEER	CH	3	31	61	90	122	147
FOR	MH	S	210	240	W	300	330
STEER	CH	179	209	241	270	298	334

Figure 54.—Typical deviation card.

a deviation card such as figure 55, in which the inner numerals in black represent the compass card itself, the outer numerals in red the corresponding correct headings. This can be made as a cardboard ring and fitted around the face of the compass on the instrument panel. The position of the numbers around the familiar compass card makes it possible to find the heading to steer with the least loss of time—especially with a compass of the type illustrated in figure 56.

If the compass reading is less than it should be, it is clear that compass north lies to the east of magnetic north, and the deviation is known as easterly deviation. If the compass reading is greater than it should be, the deviation is westerly.

It has always been customary to refer to compass deviation as "easterly" or "westerly." With a deviation card similar to those illustrated, it seems simpler to drop the old convention and merely determine the correct magnetic heading; then FOR that heading STEER the tabulated compass direction. For the application of deviation in navigational problems, see p. 116.

At some airports, magnetic stations and compass-testing platforms are available, which greatly simplify the problem of determining the correct magnetic directions. In the absence of such facilities, magnetic directions must first be determined by reference to a master compass of known deviation; by determining the direction of true north from observations of the sun or stars, and correcting for the observed magnetic variation of the place; or by other available means.

Magnetic variation is the angle between true north and magnetic north at any given place. In engineering and scientific work it is known as magnetic declination. See page 112.

Figure 56 represents a more recent type of compass, known as a "direction indicator." This instrument is more stable than the ordinary
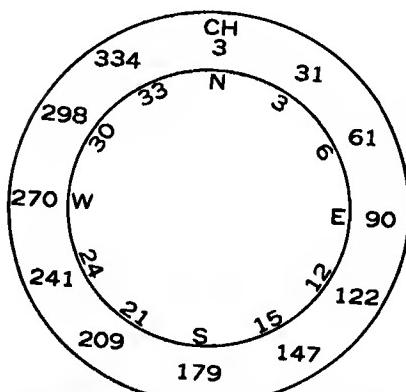
Figure 55.—Alternate form of deviation card.
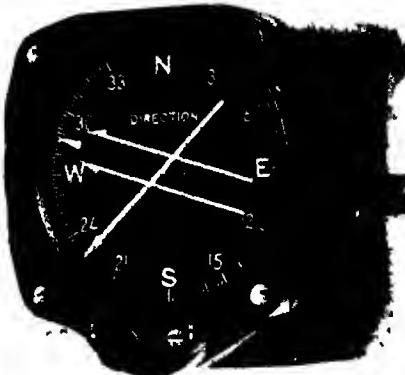
Figure 56. -The "direction indicator," a more recent compass.

magnetic compass. The compass card is fixed and the needle indicates the heading of the aircraft. In flight, the parallel reference lines can be set to the desired heading, and the airplane is flown so that the needle is kept parallel to the reference lines.

The gyro flux gate compass has been developed for military use during the present war, and furnishes a very stable indication of direction. More important, it retains its sensitivity and usefulness even within 100 or 200 miles of the magnetic poles, where the ordinary compass is useless (see p. 308).

THE TURN-AND-BANK INDICATOR

The only usable readings of the ordinary magnetic compass are those that are obtained in straight and level flight. The compass cannot be relied upon to indicate the degree of turn except by comparing the original

compass heading with the heading after a turn has been completed and the compass has come to rest.

In order to maintain straight and level flight, a turn-and-bank indicator (fig. 57) is commonly used in conjunction with the compass. Any turn toward the left or right is indicated by a corresponding deflection of the hand of the turn indicator. If the turn is properly executed, the steel ball remains centered in its tube; if the controls are not properly coordinated for the turn, the ball skids outward from the turn, or falls inward.

The turn indicator is of value also in the system of timed turns used in instrument flying. It is usually calibrated so that when the hand is displaced from the central "lubber line" by a space equal to the width of the hand, a 360° turn will be completed in two minutes; that is, at the fixed or standard rate of 3° a second.

THE DIRECTIONAL GYRO

The aircraft directional gyro (fig. 58) is much the same in appearance as the magnetic compass. It has no directional properties of its own, but contains a small suction-driven gyroscope. The gyro will maintain

Figure 57.—Turn-and-bank indicator.

Figure 58.—Directional gyro.

any direction to which it is set, for a short time, but its indication of direction changes, because of precession, at the rate of about 3° in 15 minutes' time, and it must therefore be reset at frequent intervals.

Within this limitation, it accurately measures the amount of any turn, and provides the pilot a steady indication of direction, without lag or oscillation. An improved directional gyro, with a much slower rate of precession, is understood to be under development.

In flight, the instrument may be set on any arbitrary heading and used as a turn indicator until the magnetic compass has come to rest. It may then be set to agree with the observed compass heading. Another

method is to use the gyro as a turn indicator until the compass card indicates the desired course, then set the gyro to zero. It is easier to hold the airplane's head on zero than on some heading requiring the frequent reading of a particular number of degrees, as 205°.

When performing acrobatics or other maneuvers requiring any extreme degree of tilt, the knob should be pushed in, and the gyro "caged" until normal flight is resumed. It may then be checked against the compass again, and reset.

The directional gyro is particularly valuable for navigation near the poles, where the weaker horizontal magnetic field and the rapidly changing magnetic variation make the ordinary magnetic compass almost worthless. Special methods have been worked out for setting the gyro under these conditions, with the aid of the astro compass, as described in Chapter XI.

THE ARTIFICIAL HORIZON

The artificial horizon consists of a horizon bar maintained in horizontal position by an air-driven gyroscope, and a tiny silhouette of an air-
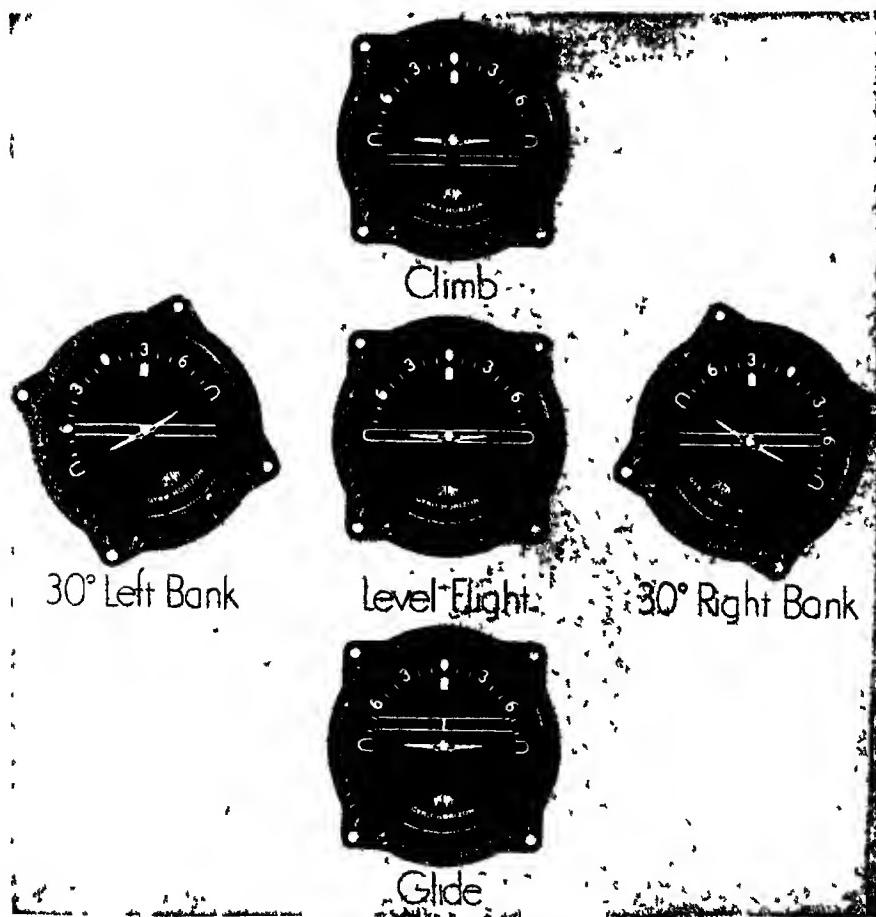
Figure 59.—Artificial horizon.

plane which is in reality a part of the airplane structure, and therefore tilts in the same manner as the actual airplane. If the airplane climbs or descends, the horizon bar seems to fall or rise in the same way that the actual horizon seems to move when viewed by the pilot. Figure 59 shows the artificial horizon as it indicates varied positions of an airplane in flight.

RADIO INSTRUMENTS

Radio is of ever-increasing importance in air navigation, and there are a number of radio instruments suited to the needs of all types of flying.

A simple **radio receiver** has become almost a necessity, even in the light airplane. With it, radio range signals and weather reports may be received while in flight, and instructions may be received from the traffic control tower at the airport, upon taking off or upon completion of the flight. There are already a number of commercial airports where aircraft not equipped with radio are forbidden to land.

A two-way radio makes it possible for the pilot to communicate with the various ground stations while in flight, requesting weather reports or other essential information, reporting his estimated time of arrival, or requesting permission to alter his flight plan.

Figure 60.—Radio compass indicator.

The **radio compass** makes use of the directional properties of a loop antenna. The loop in this case is fixed (nonrotatable), and as long as the airplane is headed directly toward the radio station to which it is tuned, the indicator hand (fig. 60) remains centered. Any turning away, toward the right or the left from the station, results in a corresponding deflection of the indicator hand. The radio compass is chiefly used for "homing flight" toward or away from a radio station.

The **radio direction finder** makes use of a rotatable loop, which is rotated until an aural null (absence of audible signal) is obtained. In this position, a movable hand indicates on an azimuth scale the angle between the heading of the airplane and the direction to the radio station. This angle is known as the "relative bearing" of the station. The same information for two or more radio stations, when converted to true bearings and plotted on a suitable chart, determines the position of the airplane. In recent instruments the azimuth scale reads up to 360°, and may be set for the true heading of the aircraft, after which the bearing of a radio station from true north may be read directly. For the method of plotting radio bearings see pages 223 to 229.

With the **automatic direction finder** it is only necessary to tune in the desired radio station; the loop then rotates automatically to the null position, and the hand on the dial points continuously toward the station. The scale on the dial is movable, and may be set so that either the magnetic bearing, or the true bearing of the station is read directly. Figure 61 shows the indicator of an automatic direction finder.
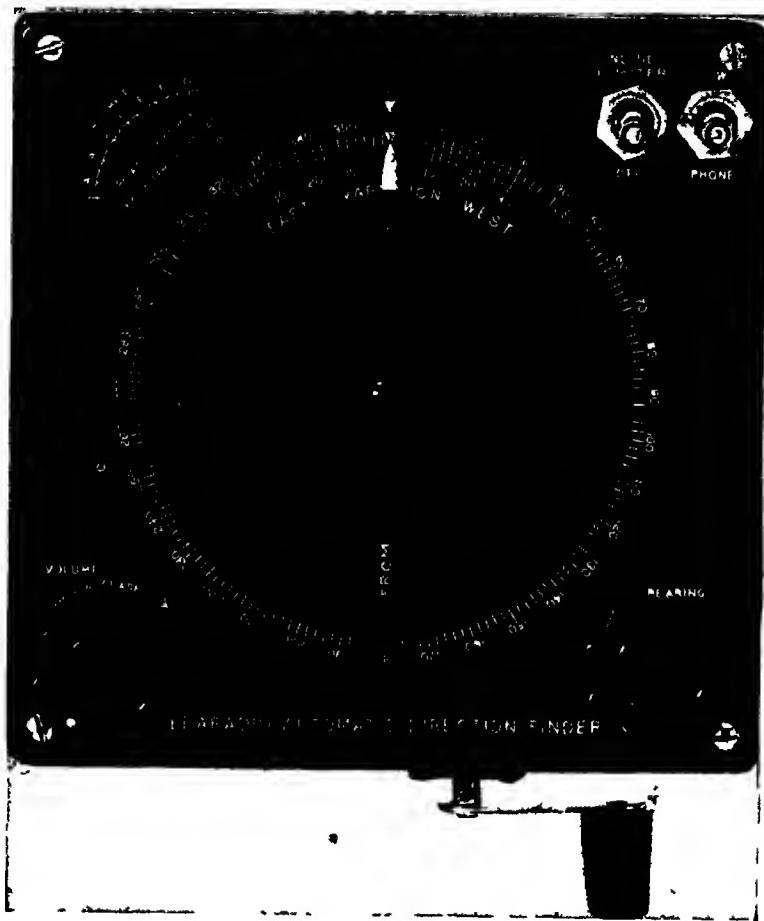
Figure 61.—Automatic radio direction finder.

The **radio altimeter** measures the actual height of the airplane above the ground level, rather than the height above sea level. It is also known as the "absolute altimeter," or "terrain clearance indicator." It offers many possibilities, but further development will probably be necessary before it becomes of interest to pilots of the smaller aircraft.

Radar is a further development of the same principles, and furnishes distance from a radio station. Distances from two or more radio stations, of course, determine position. Other important radio methods have come into use during the war, but cannot be discussed now.

THE ASTRO COMPASS

This instrument is intended primarily as a means for obtaining direction from the sun and other heavenly bodies, and is constructed in much the same way as the ordinary equatorially mounted telescope. It may be adjusted for the latitude of the observer and also for the position of the body being observed. Figure 62 shows the astro compass mounted in the navigator's "blister," or astro-dome, of a large airplane.
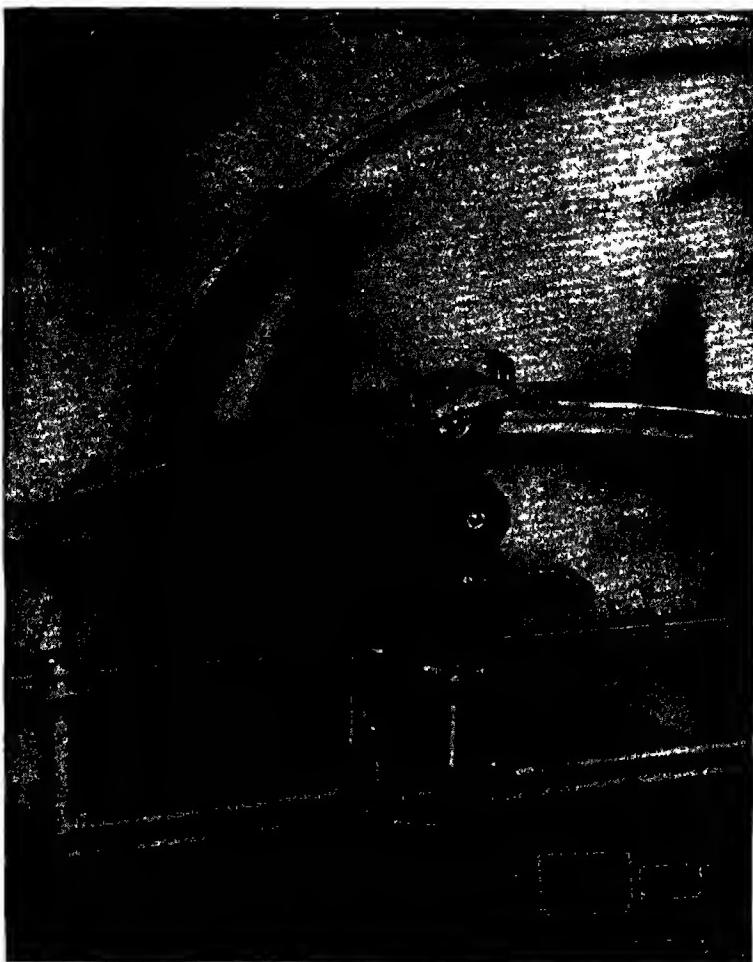
Figure 62.—The astro compass.

With the above adjustments made, the relative bearing of the body (determined as explained in Chapter X) is set against the lubber line, shown at the right of the instrument, and the airplane turned until the sun's shadow falls upon the center line of the translucent screen at the top of the device; the aircraft is then on the correct heading. If the direction of a star is to be used, the aircraft is turned until the star can be sighted between the points of the sighting vane at the top.

If the latitude scale is set at 90° and the declination scale at 0°, the instrument may be used as a pelorus for taking visual bearings on any

object. The use of the astro compass in polar navigation is discussed in Chapter XI.

QUESTIONS

1. What two primary functions are served by navigational instruments?

2. What is meant by "standard atmosphere?"

3. Is the indicated air speed at 5,000 feet too great, or too little? By approximately how much?

4. What is the effect of higher-than-standard temperature on the indicated air speed?

5. State the approximate rule for obtaining the true air speed from the indicated air speed.

6. At 6,000 feet the indicated air speed is 120 mph; what is the approximate true air speed?

7. The indicated stalling speed of an aircraft at sea level is 50 mph; at what indicated air speed will it stall at 8,000 feet?

8. Explain the principle of the ordinary altimeter.

9. What is the purpose of the barometric scale on an altimeter?

10. Why is it important that the barometric scale always be set to the current altimeter setting?

11. Under what conditions will an altimeter indicate altitudes higher than the true altitude? Altitudes lower than the true?

12. State the rule for the approximate altitude error.

13. When flying from a high pressure area into lower pressure, what will be the effect on the altimeter?

14. Define pressure altitude.

15. Can wind direction and velocity be determined directly, by instruments, while in flight?

16. Can the correction for drift be determined from the observed drift angle?

17. Name several reasons why drift sights have not been more generally used in commercial and private aircraft.

18. What instrument is chiefly depended on for indication of direction in flight? What are its principal errors?

19. Why does the magnetic compass fail to indicate correctly when banked for a turn?

20. Name the 16 points of the compass in order, beginning with north and proceeding in a clockwise direction (this is known as "boxing the compass").

21. State the number of degrees corresponding to each of the 16 points of the compass.

22. Define magnetic variation.

23. Does compass deviation ever change? Why?

24. Why is a 90° turn seldom indicated by a difference in compass heading of exactly 90°?

25. Using a compass card with deviations as shown in figure 54, what compass headings should be flown in order to make good the following magnetic headings: 130°; 215°; 315°; 160°?

26. How is the turn-and-bank indicator used in connection with the magnetic compass?

27. How is the directional gyro used with the magnetic compass?

28. What accuracy may be expected of the directional gyro?

29. Describe the artificial horizon and its functioning.

30. What is the value of a simple radio receiver in a light airplane? of two-way radio?

31. Distinguish between a radio compass, a radio direction finder, and an automatic radio direction finder.

32. What is meant by a radio altimeter, and in what way do its indications differ from those of an ordinary altimeter?

Chapter V.—CHART READING

DISTINCTIVE PROPERTIES OF CHARTS

The distinction usually made between maps and charts is that a chart is a representation of an area consisting chiefly of water; a map represents an area that is predominantly land. It is easy to see how this distinction arose, in the days when there was no navigation over land, but a truer distinction is that charts are specially designed for use in navigation, whether at sea or in the air.

Charts are intended not only to furnish an accurate representation of an area, but also to serve as a suitable base for the plotting of the problems of navigation in order to arrive at an accurate solution. The safety of life and property demands the greatest care and accuracy in all details.

In the preparation of maps definite conventions have developed, evaluating the relative importance of features to be mapped and the emphasis to be given each. Aeronautical charts, designed for one special purpose, often violate the established usage of conventional maps; items which would normally be included in any ordinary map are often omitted in order not to obscure details of greater importance to the navigator; other features are sometimes exaggerated beyond topographic justification, because of their landmark value.

The aeronautical charts include approximately 35,000 miles of airways equipped with landing facilities, beacon lights, radio ranges, teletype service, weather reporting stations, and other related features. Over such an extensive system it is clear that many changes must occur: New airways are being established and old routes rebuilt for more efficient operation; routes have been extended into Alaska, and transocean navigation by air has become commonplace.

Once the information on a chart becomes obsolete, its further use for navigation is a definite hazard. Considerable time and effort are therefore expended in the frequent correction of charts, to show the changes in information as they occur. This is a most important function of the Government, and is imperative for safety in all forms of air transportation.

THE IMPORTANCE OF CHART READING

An aeronautical chart may be defined as a small-scale representation of a portion of the earth and its culture, presenting to the trained eye a description of the charted region more nearly perfect than could be

obtained from the pages of a book. It depicts the landmarks and other information found of value by pilots long familiar with the region, and provides a working base suitable for the graphic solution of the problems of air navigation. Consequently, any time spent in learning to read and interpret its detailed information will be well repaid.

This is emphasized in a report of the Civil Aeronautics Board, investigating an accident that occurred only 2 miles from a charted auxiliary field. The report stated, in part: "Investigation also revealed that the pilot who was experienced in cross-country flying had not used the maps, which were in a closed valise in the airplane, and that he did not realize the close proximity of the emergency field." If proper use had been made of the charts in the unopened suitcase, the accident might have been avoided.

A related error is reliance upon a single selected landmark, such as a road or railroad, for guidance. In another accident report, after explaining that the pilots had intended to follow a particular road, it is stated that "they must have followed some other highway." This accident might have been avoided if the pilots had been trained to check by *combinations* of landmarks, instead of a single feature—for example, the same highway with respect to railroads, stream patterns, towns, or grain elevators.

In still another report it is stated that "strong contributing factors were the pilot's failure (1) to equip himself with an up-to-date aeronautical chart and (2) to utilize the radio aids available to him to accurately establish the position of the flight while on instruments." These and many similar incidents all emphasize the importance of learning to read the detailed information on the charts—ALL of it—quickly and easily.

In charting the details of the terrain and the system of aids to navigation, many conventional symbols are employed. Some of these have been in use for many years, and their significance is generally understood; others have been adopted more recently and are of more specialized use, and therefore are not as well known. The following description of these symbols and their significance has been prepared as an aid to chart reading. It applies primarily to the revised sectional charts [2] (see Plate IV), since the scale of that series permits the charting of fairly complete information. On the smaller scale charts many details must be omitted, but with few exceptions those that can be included are shown by the same symbols.

The features shown on these charts may be divided into three groups:

1. **Topographic information** necessary to a clear and accurate representation of the region.

2. **Aeronautical data** and information of interest chiefly for air navigation.

[2] A complete revision of all sectional charts is now in progress (1944). Where the revised charts differ in treatment from previous editions, attention will be directed to the changes.

3. **The legend,** and other written notes describing the projection, and miscellaneous information on the chart.

The topographic features may in turn be subdivided into three groups:

a. Drainage, including streams, lakes, canals, swamps, and other bodies of water.

b. Culture, such as towns, cities, roads, railroads, and other works of man.

c. Relief, including mountains, hills, valleys, and other inequalities of the land surface.

TOPOGRAPHIC INFORMATION

DRAINAGE FEATURES

[See fig. 63]

Drainage features are generally represented on the aeronautical charts in blue, the smaller streams and canals by single blue lines, the larger streams and other bodies of water by blue tint within the solid blue lines outlining their extent.
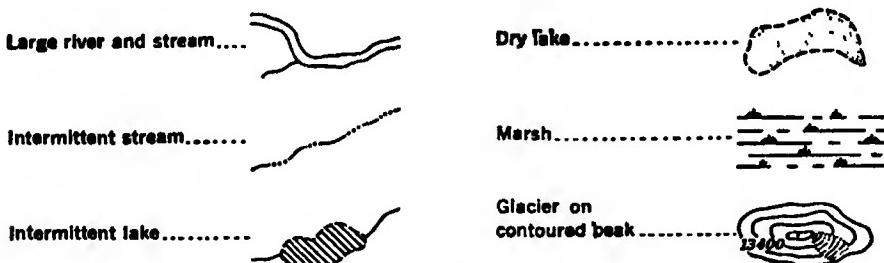
Figure 63.—Drainage features.

Intermittent streams are shown by a series of long dashes separated by groups of three dots, suggesting the scattered pools into which the diminished streams sink during the dry season.

Intermittent lakes and ponds are shown with broken shore line and cross ruling in blue.

In some sections of the country, the beds of dry lakes and ponds are conspicuous landmarks. Such features are indicated by brown dots within the broken "shore line" of blue.

Marsh areas are shown by horizontal blue lines, with scattered groups of short vertical dashes suggesting the clumps of marsh grass common in such areas.

Glaciers are indicated by blue shading, representing the form and the flow lines of the glacial area.

Reservoirs are shown in the same way as lakes, but usually with the dam symbol indicated in black (or, sometimes, in blue). They may be either permanent conservation pools, or storage pools for flood control. Flood control pools are emptied as soon as practical after floods, and

their size and shape may differ appreciably from those charted. In the same way, for some little time after heavy rains, "lakes" may appear where none are shown on the chart, and the swollen streams that look like broad rivers in the spring may be quite inconspicuous during the dry weather of summer.

CULTURAL FEATURES

[See fig. 64]

Among the more prominent cultural features are the cities, towns, and villages. It is not possible to show all of them, so a selection is made based not only on population but also on relative importance in a given area, with particular attention to *aeronautical* importance. A town of 600 people near New York City would have little meaning on an aeronautical chart, but a town of the same size in the sparsely settled west would be of considerable importance—especially if it had a good airport.

Figure 64.—Cultural features.

For the sectional charts of the United States, where excellent information is generally available, cities and towns are divided into seven classes, as follows:

1. Towns in which there is no greater concentration of buildings or people than in the surrounding countryside; usually omitted from the chart.

2. Towns showing a small but definite cluster of buildings, easily distinguishable from the more scattered buildings in the vicinity. These may range from 5 or 6 houses to about 15 buildings; usually shown on the sectional charts, in thinly settled areas, by small black circles.

3. Towns from about 15 buildings to 60 or 70 buildings. These are shown by larger black circles in thinly settled regions, where they are fairly prominent; by small black circles in more thickly settled areas; in densely populated sections they may be omitted altogether.

4. Towns from 800 or 1,000 to about 5,000 in population; shown by a yellow square on all sectional charts, except in the most congested areas, where they may be shown by the larger black circles, or may even be omitted.

5. Cities from about 5,000 to 25,000.

6. Cities from about 25,000 to 100,000.

7. Cities over 100,000. For cities of classes 5, 6, and 7, the actual shapes of built-up areas are shown in yellow, outlined by a fine black line.

For smaller scale charts, the smaller black circle is not used, and there is a tendency to reduce the classification of many cities and towns one step. This is necessary, to prevent crowding the chart with large symbols and place names.

Railroads are represented by fairly heavy black lines with crossties at about 4-mile intervals, interurban electric railways (trolleys) by lighter black lines with crossties at about 2-mile intervals. The spacing of crossties is subject to some variation, and is without significance except as an aid to identification.

Single-track railroads are shown with single crossties, while for railroads of two or more tracks the crossties are in pairs.

Even if a railroad has been abandoned or torn up, the old roadbed is sometimes a prominent feature when viewed from the air; when this is the case, it is indicated on the chart by a broken black line with crossties.

Tunnels are indicated not only because they serve as landmarks, but also because they are a source of potential danger. If a pilot is following a railroad through territory with which he is not familiar, and the railroad enters a tunnel, he may find himself suddenly deprived of the one landmark upon which he was relying, or even confronted by a mountainside, without sufficient space either to turn or to climb above it. This difficulty is seldom encountered in the case of highways, but any highway tunnels are shown by the same symbol.

Highways are shown by a black double-line symbol, the lines being a little heavier and wider spaced for prominent highways than for secondary highways. Superhighways (usually divided-lane highways) are shown by a triple-line symbol, the center line (which may be either solid or broken) suggesting the multi-lane feature.

The highway route number, centered within a shield, is shown at intervals along the principal Federal highways. In some States the main roads are air marked with the same numbers as an aid to identification from the air. In a few instances, in sparsely settled country where there are few other landmarks, very poor roads are charted because of their unusual landmark value, and such roads are shown by broken lines (the conventional symbol for a trail).

"Prominent highways" and "secondary highways" must be understood as only relative terms. In some of the thinly settled western districts, roads are so few that practically all of them are shown; the most important through highway may be only a well-graded dirt or gravel road,

yet it is so prominent in its own vicinity that it is charted with a heavy line. On the other hand, in the more thickly settled sections there are so many roads that it is impossible even to include all the highly improved roads.

For example, figure 65 shows all the roads in the vicinity of Navasota, Tex., according to a survey made in 1912. Only those shown by heavy lines were included on the Austin sectional chart; the roads shown
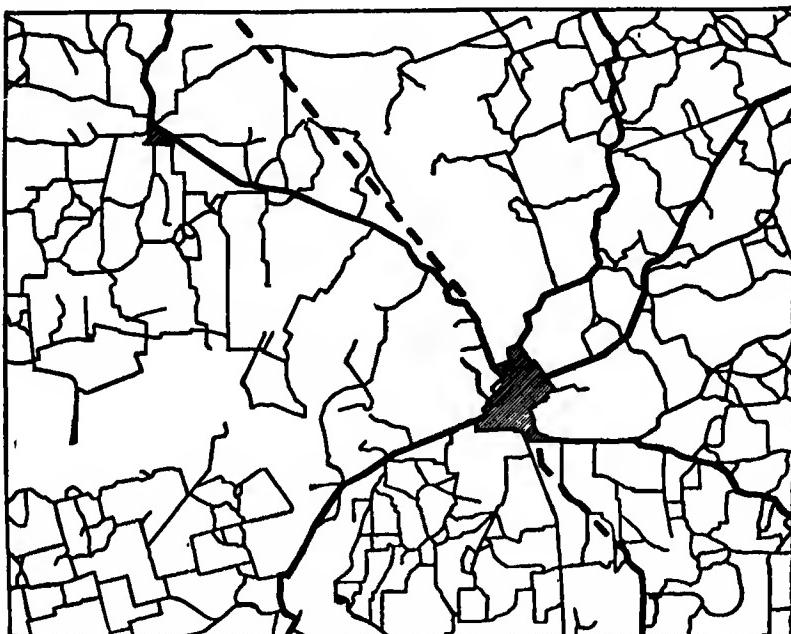
Figure 65.—Highways in vicinity of Navasota, Tex. (1912).

by a heavy broken line were constructed after the survey was made, and were added from flight check data and later sources.

The treatment of highways, then, varies with the region under consideration, but in each case an attempt is made to delineate the distinctive road pattern as it would be seen from the air.

Race tracks are prominent landmarks, and whenever possible their characteristic oval shapes are indicated in black. In congested areas where the actual shape cannot be shown, the location is sometimes indicated by a heavy dot, and the words "Race track," are printed in the nearest open space, with an arrow leading to the dot.

Lookout towers in the State and national forests are located on the highest ground in the vicinity. In some cases they have been air marked with a number, and these numbers appear on the chart adjacent to the symbols, in vertical black figures. Formerly, the elevations of the ground at the towers were added in black italics; on the revised charts the elevations of the tops of the towers above sea level are shown instead, since this is the information most vital to pilots.

A quarry, or a mine, is represented by a symbol suggesting the pick and hammer of the miner, or by a black dot and descriptive note.

A Coast Guard station is indicated by a small black "boat," accompanied by the number with which it has been marked for identification from the air.

A dam is shown by a heavy black line. In some places, as along the Ohio River, dams are accompanied by locks, and are very conspicuous from the air. The lock is indicated by a short black line at right angles to the dam, forming a sort of "T".

In addition to the foregoing, there are in many localities a number of unclassified distinctive landmarks which are of great assistance in identifying position. These are usually indicated on the sectional charts with a dot and descriptive note.

It should be understood that, even on the larger-scale charts, certain features must be exaggerated in size. For example, if a prominent highway is measured by the scale of statute miles on a sectional chart, the highway appears to be about a fifth of a mile, or more than 1,000 feet in width, but this exaggeration is necessary for the sake of clarity and emphasis. Again, in a narrow canyon it may be required to show a stream with a railroad on one side and a highway on the other. On the ground the three features may occupy a space no more than 75 feet in width, yet on the chart, showing the three symbols as close together as possible, they appear to occupy nearly half a mile, or about 2,500 feet. In the case of water features, a small lake 300 feet wide and 2,000 feet long may be an outstanding landmark; at the actual scale of the chart 300 feet would be reduced to a fine single line; it must be exaggerated in width enough to show a small area of blue tint between two limiting shore lines of solid blue, and in length enough to preserve in a general way, at least, the shape of the lake. Whenever possible, symbols are centered on their true locations and exaggerated only as much as may be essential to a clear representation.

RELIEF

[See fig. 66].

On the aeronautical charts the mean high water line is taken as the shore line. This seems fitting, since any "land" farther toward the sea would be under water part of the time. At the scale of the aeronautical charts the difference between the high water and the low water shore lines is usually indistinguishable. In areas with low, gently sloping shores, however, the shore line at low water may appear noticeably different.

While the high-water shore line is adopted, all other elevations represent heights above the average level of the sea (mean sea level). Relief is shown by contour lines in brown, and is emphasized by a series of gradient tints ranging from green at sea level to a dark brown above 9,000 feet. On a few charts in the west, extensive areas below sea level are indicated by a darker green. In the present revision of the sectional charts, in areas which have been inadequately surveyed and for which the information can be considered only approximate, contours are shown by

broken lines. Occasionally, prominent peaks or steep cliffs, considered either as a hazard or an outstanding landmark, are accentuated by hachuring.

Spot heights are also selected with the intent of showing the range of elevations—the highest danger points, and the mountain passes, or
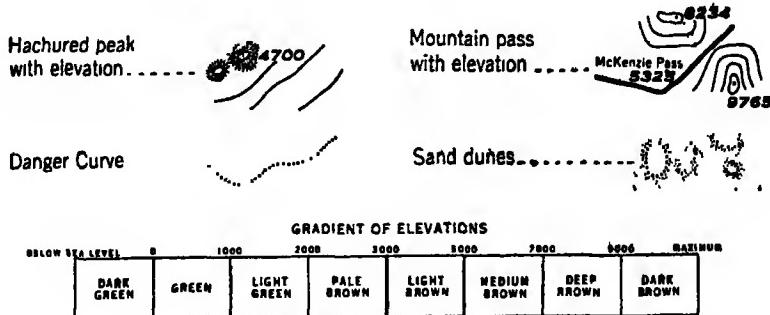
Figure 66.--Relief (elevation).

the general level of the intervening low ground. A dot on the chart marks the location of the spot to which the elevation applies. The elevations of a number of cities and towns are also shown.

A contour represents an imaginary line on the ground, every point of which is at the same height above sea level, and the varied curves of
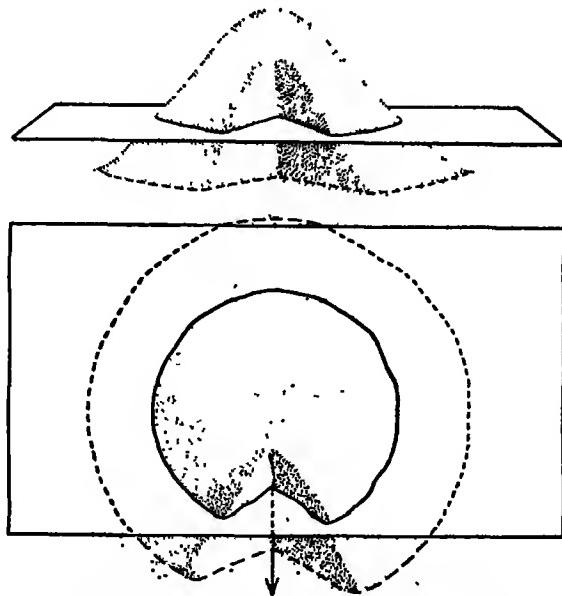
Figure 67.- Contours illustrated by a sand pile.

the contour show the ridges, valleys, canyons, bluffs, and other details. With a little practice, one may read from the contours and gradient tints not only the elevations, but also the shape of the terrain, almost as easily as from a relief map.

Any contour is the intersection of an imaginary horizontal plane with the surface of the terrain. To illustrate, figure 67 represents a pile of sand from the nearer side of which sand has been carried away until a "valley" has been formed. The top of the sand pile is 5 feet above the pavement, and an imaginary plane is passed through the pile at a height of 2 feet. In the lower part of the figure is shown the "2-foot contour," or the trace of the intersection of the plane with the sand. The trace of the lower edge of the pile of sand on the pavement may be considered as the "shore line," or the line of zero elevation.

If it were raining, water would flow down the "valley" in the direction indicated by the arrow, which may be considered as a "stream." Thus, we see that when contours cross a stream they bend toward the source of the stream which is, of course, on higher ground; conversely, when crossing a ridge the contours bend away from the higher ground.

In figure 68 the curves at *V*, *V*, *V*, represent valleys of varying width and depth, while *R*, *R*, *R*, represent ridges or hills.

One way of visualizing more readily the significance of the contours is to think of them as successive shore lines if the sea should rise to the levels indicated by the respective contours. The line of the seacoast itself is a contour, every point thereon having the same elevation (zero) with
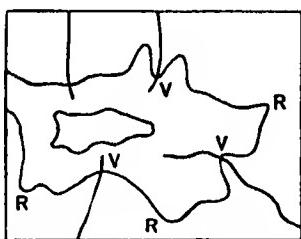
Figure 68.—Ridges and valleys shown by contours.
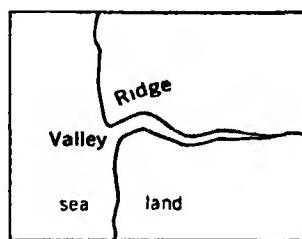
Figure 69.—The seashore as a contour.

respect to mean high water. Any valleys running down to the shore line are represented by a curve or indentation landward; any ridges result in a curve seaward (fig. 69). Now if the sea should rise 1,000 feet, the 1,000-foot contour would become the shore line; valleys would still be indicated by a curve toward the higher ground (which could now be called "landward"), and ridges would be indicated by a curve toward the lower ground ("seaward").

If a cliff should rise almost vertically above the shore line for 1,000 feet, the 1,000-foot contour would appear on the chart very close to the shore. When the terrain slopes gently upward from the coast, the 1,000-foot contour is a considerable distance inland. Thus, contour lines that are far apart on the chart indicate a gentle slope, while lines that are close together indicate a steep slope; contours that run together indicate a cliff. Many people believe that contours can never cross, but this would occur in the case of an overhanging cliff.

To obtain a clear picture of the significance of contours, on a semi-circular piece of paper draw a series of semicircles at intervals of about

2 inches, as illustrated at the left of figure 70. Now roll the paper into an ordinary "dunce cap," and pin it so it will not come undone. It will appear as in the center of the figure, with the horizontal lines representing contours having successive differences in elevation of about 2 inches.
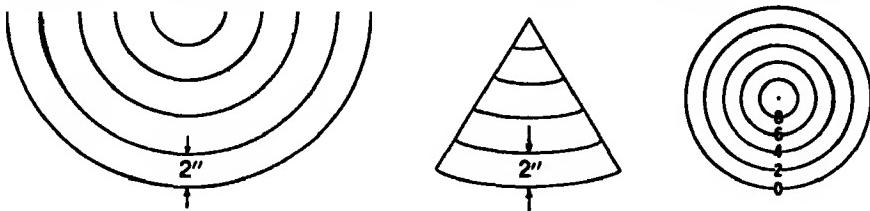
Figure 70.—Contours illustrated by a dunce cap.

If we set the dunce cap on the floor and look straight down upon it (which is the way the earth's surface is represented on a chart), the system of "contours" will appear as at the right of the same figure.

Now, if we crease a "valley" into one side of the dunce cap, the two views will appear as in figure 71. If this were a real valley, a stream would probably be flowing down it, as represented by the broken line. Note, again, that where contours cross the stream they bend toward the source of the stream; where contours cross a ridge, the opposite is true, and they bend away from the higher ground.
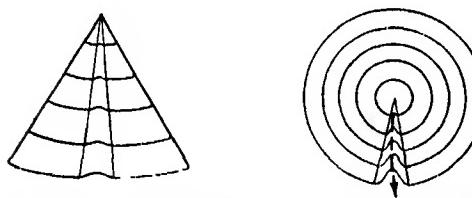
Figure 71.—The dunce cap with "valley" and "stream."

The manner in which contours express elevation, form, and degree of slope is shown in figure 72. The sketch in the upper part of the figure represents a river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked sand bar. On each side of the valley is a terrace into which small streams have cut narrow gullies. The hill on the right has a rounded summit and gently sloping spurs separated by ravines. The spurs are cut off sharply at their lower ends by a sea cliff. The hill at the left terminates abruptly at the valley in a steep and almost vertical bluff, from which it slopes away and forms an inclined tableland that is traversed by a few shallow gullies. In the lower part of the figure, each of these features is represented, directly beneath its position in the sketch, by contour lines.

In figure 72 the contours represent successive differences in elevation of 20 feet—that is, the "contour interval" is 20 feet. For the revised sectional charts a 500-foot contour interval has been adopted for all charts east of the 102nd meridian. This interval brings out the shapes of the ridges and develops many of the tops more satisfactorily than the 1,000-foot interval previously used. West of the 102nd meridian, as the Rocky Mountains are approached, the country is steeper and more rugged; contours at 500-foot intervals are too crowded, and the 1,000-foot interval has therefore been retained.

For all regional charts, the contour interval is 1,000 feet. For the smaller scale charts the intervals are still greater.

In order to maintain a safe flying altitude, unless the elevation of the top of a ridge or peak is given in figures, it should be assumed that
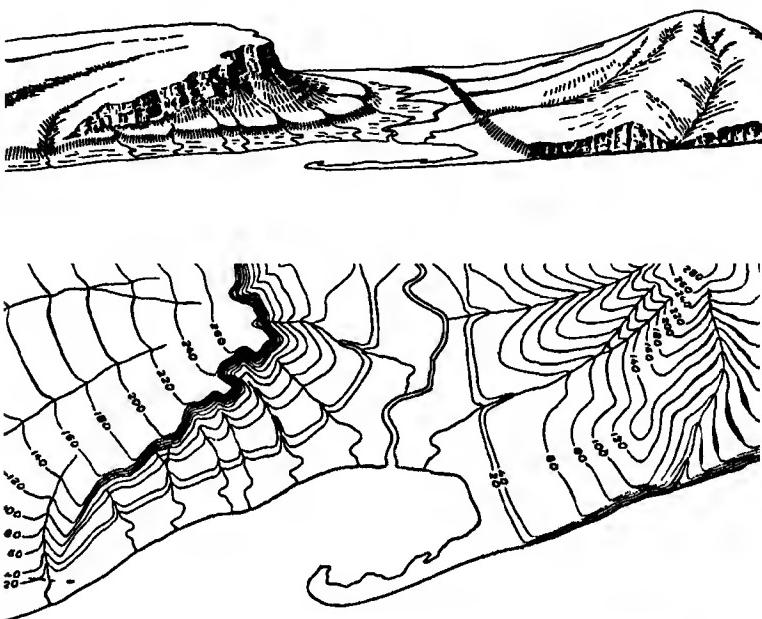
Figure 72. Altitude, form, and slope expressed by contours. (After U. S. Geological Survey).

the elevation extends all the way to the next contour above the highest contour shown. For example, the highest charted contour along a ridge may be only 2,000 feet, yet the ridge may be topped by minor summits rising to 2,400 feet or more. Assuming trees approximately 100 feet in height, the extreme elevation of the ridge may be almost 2,500 feet, yet the information available to the cartographer does not warrant the addition of the 2,500-foot contour. It should be noted that the gradient tint used in this case, pale brown (see fig. 66), indicates not merely an elevation of 2,000 feet, but includes any elevation short of 3,000 feet. Unless absolutely certain of their position, whenever visibility is poor, pilots should be careful to fly at a safe margin above the highest ground in the entire region.

The danger curve, in water areas (fig. 66), may be thought of as an under-water contour. In most cases on the revised charts it may be thought of as a curve every point of which is 6 feet below low water. In some instances it merely encloses an area of uncertain depth that is known to be dangerous for seaplane operations. On the earlier editions it was shown as the 3-foot depth curve, and seaplane pilots should check

this information in the marginal legend. It is shown by a row of black dots. At the scale of the sectional charts it is impossible to show danger areas in satisfactory detail, and pilots should never rely upon this information for landing.

Sand and sand dunes are indicated by brown dots (fig. 66).

All the foregoing features are combined by the cartographer in such a manner as to reproduce the characteristic details of the region accurately, but without confusion. Then to this basic topographic representation are added those features of special interest for air navigation.

AERONAUTICAL DATA
AIRPORTS
[See fig. 73]

Aeronautical information and features of interest chiefly for air navigation—such as airports, beacon lights, radio ranges, radio call letters, and identification signals—are shown in red.

Airports are classified as to their operation (whether commercial, municipal, Army, etc.), and also as to their service facilities. They are shown in accordance with figure 73. It is important to consider the clas-

Army, Navy or Marine Corps Field	◯	Emergency Landing Field	✛
Commercial or Municipal Airport . . .	☼	Unclassified Airport	⊕
Joint Military Civil Airport . . .	◯	Seaplane Base . . . . (with complete facilities)	⊕
C A A Intermediate Field (with course lights)	⟁	Seaplane Anchorage . . . . . (with refueling and limited facili	
Flight Strip . . . . (landing area adjacent to highway) (symbol indicates direction of runway)	⊖	Protected Anchorage . . . . (no facilities)	⌐
	Mooring Mast . . . . ⌐		

Figure 73.—Airport classification.

sification of a field before landing, as civilians cannot obtain supplies or service at an Army or Navy field. (NOTE: All Army and Navy airports and other defense facilities have been deleted from plates I to IV, for reasons of military security.)

New symbols for airports and other aids to air navigation have recently been adopted and may be found on aeronautical charts by the summer of 1945. Their significance is explained in plate V, following p. 351. They will also be explained in the legends of the charts on which they appear.

In the absence of other suitable airports, the intermediate fields of the Civil Aeronautics Administration are established at intervals of about 50 miles. They are intended primarily for emergency use, but are also available for noncommercial flying activities; under certain conditions they are even available for occasional commercial use.

In addition to facilities for landplanes, a number of seaplane bases have been established inland, providing for practical and economical seaplane operations from coast to coast, and from border to border.

With the growth of international air traffic, information regarding airports of entry (customs airports) has become increasingly important Accordingly, when an airport has been designated as a port of entry, this fact is noted on the chart, near the airport name.

Elevations of airports above sea level are indicated by inclined numerals adjacent to the airport name.

The symbol for an unclassified airport is never used for airports within the United States. In the case of flight strips, the direction of the diagonal stroke indicates the orientation of the landing strip.

The letters *LF* indicate that the field is equipped with lighting facilities for landing at night. Sometimes these facilities are operated only at certain hours, or on request. The same is true of certain other beacon lights and aids, and for complete information on these points pilots should contact the nearest CAA communications station, or obtain local information.

As a defense measure, all radio aids and lighting facilities, especially along the coasts, are subject to complete shutdown without notice.

For easy reference in traffic control and for related purposes, airport runways are now numbered and ground-marked with the magnetic directions in which they are to be approached. In each case, they are numbered to the nearest 10°, and the final 0 is omitted. For example, if a runway lies east and west (magnetic), the east end would be numbered 27, representing 270°, the direction of approach for an airplane landing from east to west; the west end of the same runway would be numbered 9 (representing 90°).

OTHER AERONAUTICAL DATA (MISCELLANEOUS)

[See fig. 74]

A rotating beacon is indicated by a star with open center, accompanied by its "site number." If the beacon is equipped with course lights, the code signal corresponding to the site number, which is flashed by the course lights for identification at night, is also shown. Course lights are aviation green in color when adjacent to a lighted field; aviation yellow when adjacent to a day field (unlighted); and red when there is no field nearby. When there is a power shed at the beacon, the site number is also painted on the shed roof for daylight identification (see fig. 2). During the present emergency such markings have been removed from installations within 150 miles of the coasts.

The number of any intermediate field or beacon is obtained by dropping the final digit of the mileage from the origin of the airway on which it is located. For example, beacon No. 19 on any airway is approximately 190 miles from the origin of the airway. The course lights flash the code for only the last figure of the beacon number, the code signals being the

same for beacons numbered 9, 19, 29, etc. Beacons having the same signal are approximately 100 miles apart, and a pilot should know on
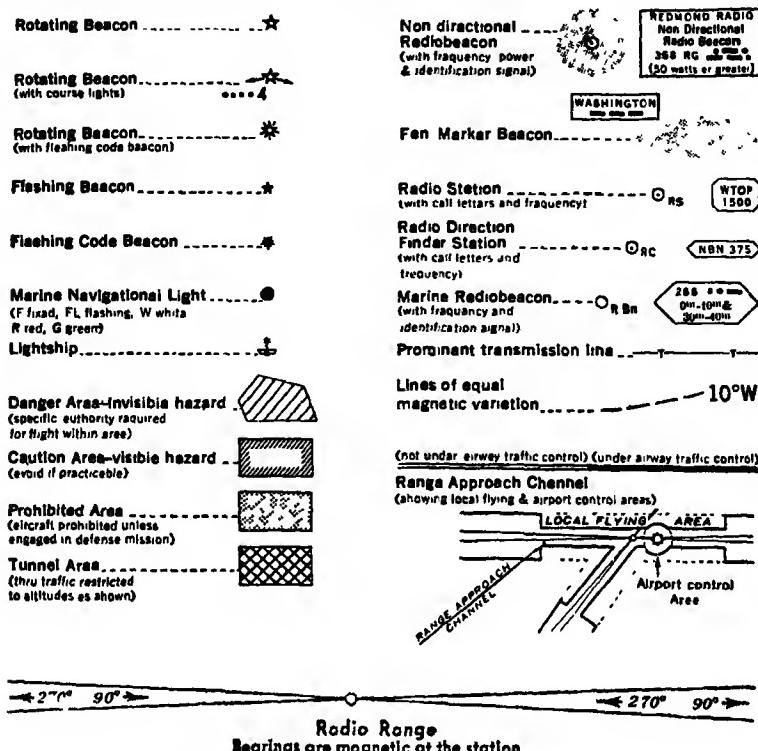
Figure 74.—Aeronautical data (miscellaneous).

which 100-mile section of the airway he is flying. The code used along the airways is shown in the following table:

TABLE 4.—*Code adopted for airway use*

A ._	M _ _	Y _ . _ _
B _ . . .	N _ .	Z _ _ . .
C _ . _ .	O _ _ _	1 . _ _ _ _
D _ . .	P . _ _ .	2 . . _ _ _
E .	Q _ _ . _	3 . . . _ _
F . . _ .	R . _ .	4 . . . . _
G _ _ .	S . . .	5 . . . . .
H	T _	6 _ . . . .
I . .	U . . _	7 _ _ . . .
J . _ _ _	V . . . _	8 _ _ _ . .
K _ . _	W . _ _	9 _ _ _ _ .
L . _ . .	X _ . . _	0 _ _ _ _ _

At some places the rotating beacon is supplemented by an auxiliary beacon which flashes an identifying code signal. In this case rays are

added to the rotating beacon symbol and the code signal flashed by the auxiliary beacon is placed nearby.

A flashing beacon, or other nonrotating beacon, is indicated by a solid star, smaller than the rotating beacon symbol; for a beacon flashing in code, rays are added around the star.

If an airport is equipped with beacon light, the proper beacon symbol is placed in the center of the airport symbol.

A light for marine navigation is shown by a large dot. A powerful light of this kind is often inconspicuous from the air, because its light is directed along the surface, for the benefit of surface navigation.

A landmark beacon, operated by private interests or by a commercial establishment for advertising purposes as well as for the benefit of airmen, is represented by the proper beacon symbol (rotating or flashing), as described above. As a rule these beacons are located neither on an established air route nor at an airport, but they serve to identify a point from which a pilot may proceed to his destination. A rotating landmark beacon usually rotates at two revolutions per minute, in order to distinguish it from an airway beacon, which makes six revolutions per minute. An arrow in conjunction with this symbol indicates that the beacon is equipped with a directional projector; on the chart the arrow is placed so that it points to the airport toward which the projector is directed.

Areas in which the flight of aircraft is prohibited or restricted are classified as caution areas, danger areas, and prohibited areas.

Caution areas are those in which visible hazards to flight exist. They should be avoided in flight when practicable.

Danger areas are those in which invisible hazards to flight exist. Flight in these areas without specific authority from the agency having jurisdiction therein is forbidden.

Prohibited areas are established by Executive Order of the President, and may not be flown over except by military aircraft actually engaged in defense missions.

All such areas are shown on aeronautical charts as indicated in figure 74. Notice of any changes or additions is given in the "Weekly Notice to Airmen," published by the Information and Statistics Service, Civil Aeronautics Administration.

A "vital defense area" is one within which the operation of aircraft is prohibited or is authorized only subject to prescribed conditions. In an "active air defense zone," civilian cross-country flights require two-way radio, and a flight plan approved by the Interceptor Command.

"Traffic tunnels" are portions of an airway within which flight must be between specified minimum and maximum altitudes. They may be further described as portions of an airway having both a ceiling and a floor. The altitudes between which flight must be conducted in these tunnels are indicated by a prominent note, enclosed in an adjacent "box."

Pilots are particularly cautioned to observe all regulations pertain-

ing to flight in these areas, or near Army and Navy installations, since airplanes approaching them may be fired upon without notice.

Prominent transmission lines are shown by a symbol representing the poles, or towers, with wires between. These lines may be considered either as landmarks or as obstructions, and because of their importance to air traffic they are shown in red. Usually, only steel tower lines are shown on the aeronautical charts of the United States, but occasionally pole lines are shown if they are prominent when viewed from the air. This is especially true in areas devoid of other landmarks.

A radio range station is indicated by a dot within a small circle, and the positions of the range courses are shown by a pink tint. Magnetic bearings toward or away from the station are indicated, and the A and N quadrants of the system are marked along the range courses, to avoid any confusion as to quadrant designation. The method of flying the radio ranges is treated in detail in a later section.

A radio marker beacon was formerly indicated by a circle of pink tint, only a few miles in diameter, the size of the circle indicating the
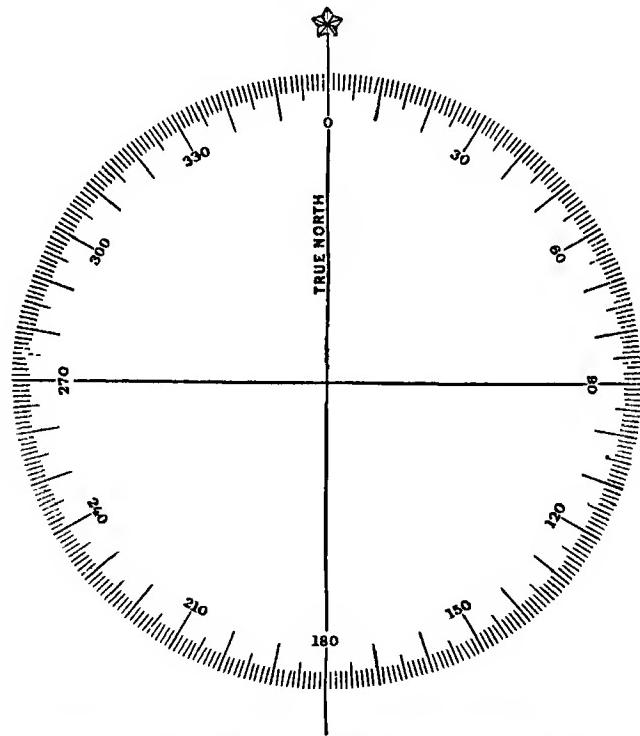
Figure 75. - True compass rose (sectional and regional charts).

limited area within which its signals might be received. These stations have now been generally discontinued, and the former marker beacon symbol is used for the newer nondirectional radio beacons, with the addition of a circle-and-dot symbol at the center to establish definite location. These are of two classes: power greater than 50 watts, and

power of 50 watts or less. The latter is known as an "MH" radio beacon, and its service area usually does not exceed 25 miles; the former is designated as an "H" (Homing) radio beacon, and may be received at greater distances.

Fan-type marker beacons are shown by pink ellipses, suggesting the space pattern of these beacons and also their sending range.

The names, identifying signals, frequencies, and related data for the various radio stations are shown adjacent to the stations to which they apply. For aeronautical radio stations, the data are shown within a rectangle; for other radio stations the corners of the rectangle are cut off.

A number of commercial broadcasting stations are shown on the charts, since they are also of navigational importance. They are indicated by the conventional circle-and-dot symbol, with the frequency and call letters in an adjacent box. On the United States charts, stations operating at less than 500 watts usually are not charted. For stations of 500 to 1,000 watts, the power is indicated on the chart as some guide to the distance at which satisfactory reception may be expected. For stations of 1 kilowatt or more, the power is generally omitted. In Alaska and other outlying areas, stations of much lower power are sometimes charted.

Radio direction finder stations are indicated by circle-and-dot symbols and the initials *RC* (from their former designation as "Radio Compass" stations). Marine radio beacon stations are indicated by the same symbol and the initials *Rbn*.

Places at which the magnetic variation is the same in direction and magnitude, are connected on the charts by broken lines known as lines of equal magnetic variation, or isogonic lines. The amount and direction of variation are also shown. In some areas unusual magnetic variation exists, and a warning note to that effect is printed in red in the area affected. It appears, however, that these unusual surface conditions cannot be detected at ordinary flight altitudes.

Compass roses (fig. 75), oriented to true north, are printed on the sectional and regional charts. If a protractor is not available, these roses may be used for the approximate measurement of courses and bearings. Because of the convergence of meridians in the Lambert projection, some inaccuracy is introduced if a compass rose is used for the measurement of direction at a point more than 1° or 2° of longitude away. On some charts, the direction and amount of magnetic variation are indicated on the compass roses, in addition to their representation by isogonic lines.
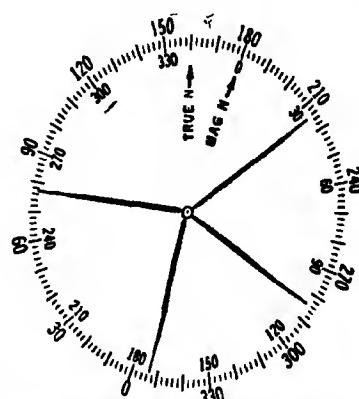
Figure 76.—Magnetic compass rose (radio direction finding charts).

Specially designed compass roses (fig. 76), oriented to magnetic north, are used on the radio direction finding charts. These roses are graduated to read both from magnetic south and from magnetic north. The outer figures are ordinarily used, and are therefore larger; they are intended for use in plotting reciprocal bearings (the radio compass bearing observed at the airplane plus or minus 180°), and for that reason read from 0 at magnetic south. For certain other problems a rose reading from 0 at magnetic north is more convenient, and for such problems the inner (smaller) figures are also available. These roses should not be confused with the conventional compass roses appearing on the sectional and regional charts, nor used in the same manner; their special use is explained in detail in a later section.

CIVIL AIRWAYS

[See fig. 74]

A civil airway may be defined in general terms as a strip of land, together with the navigable air space above it, 5 miles on either side of the center line connecting the designated terminals and intermediate points of the airway, and extending 5 miles in all directions beyond the terminal airports.

A civil airway also includes the aids to navigation described above and other facilities which have been constructed along it: Rotating beacons at intervals of about 15 miles; intermediate fields at 50-mile intervals; radio range and broadcast stations; teletype communications; hundreds of weather reporting stations; and airway traffic control centers.

Airway traffic control centers are operated by the Civil Aeronautics Administration for the control of traffic on the civil airways.

During the present emergency the standard 10-mile width of airways is subject to various limitations. In the vicinity of certain military installations the width is reduced to 6 miles; within range approach channels it is further reduced to 4 miles. All such variations in the extent of the civil airways are indicated on the charts.

Flight along the Nation's airways is subject to Air Traffic Rules designed for the protection of all who fly. A number of airports have been designated by the Administrator of Civil Aeronautics as "control airports," and traffic within 3 miles of the center of such airports is subject to control. It is understood that this distance may shortly be increased. If the radio range station serving a control airport is more than 2½ miles from the center of the airport, then a strip ½ mile on each side of the line between their centers, and extending ½ mile beyond the station, is also included in the controlled zone. A list of control airports is included in Air Navigation Radio Aids, published at frequent intervals by the Civil Aeronautics Administration. Normally, the traffic in such an area is under the control of the local airport traffic control tower.

Airport traffic control towers are operated by Federal personnel at airports handling large volumes of civil and military traffic, and by the local management at other airports. In some cases, federally operated control towers are designated as "approach control towers," and perform some of the duties of the airway traffic control center.

Control tower personnel have immediate control over all aircraft within the control zone, communicating their instructions by radio, or by light signals for aircraft without radio. They provide pilots with data such as time checks, radio checks, altimeter settings, wind data and other weather information, other air traffic at a given time, and field conditions. They also relay information between pilots and operations offices, Weather Bureau stations, and airway traffic control centers, and issue special instructions which may be required by pilots in flight.

Airway traffic control centers are always operated by Federal personnel, and are located at or near large airports. Each center has control over all aircraft flying on the airways within its geographic area, and issues its instructions through the control tower or airway communications station nearest the aircraft in flight. To facilitate this service, special arrangements were made in June 1943, whereby communicators keep apprised of all flight conditions existing within an extensive geographical area. Any information that may assist a pilot in the safe conduct of his flight is abstracted and tabulated. Upon contacting an aircraft about to enter an area covered by such information, the communicator transmits it to the pilot.

Airway traffic control centers keep the pilot informed of other traffic in his vicinity, and see to it that there is always at least 1,000 feet of vertical separation between such aircraft, or at least 10 minutes of flying time between craft flying in the same direction and at the same altitude. They are also responsible for keeping pilots informed of important weather changes, for recommending alternate airports when necessary, and for furnishing other information of an emergency nature essential for the safe completion of the flight.

The relative functions of these two services may be summarized as follows: It is the duty af the airway traffic control center to keep continual check on the flight plans and movements of all aircraft on the airways under its control; to avoid any possibility of collision; and to bring the aircraft safely and expeditiously to the point where they can be turned over to the airport control tower for actual landing instructions.

In areas not at present served by a traffic control center, "control zones of intersection" are established at the intersections of principal airways. These zones are of 25-mile radius, usually centered at a radio range station, the intersection of two range courses, or other such designated point. Except in contact flying, pilots may not enter a control zone of intersection without permission from the local airway communications station. Within the control zone, traffic rules very similar to those on the controlled airways are in effect. The limits of such a zone are indicated on the chart by a red circle and appropriate note. On the aeronautical

charts the limits of the civil airways are shown. Airways under control of a traffic control center are outlined by a solid red line; airways not so controlled are outlined in red by a fine double line.

The various air traffic rules governing flight along the civil airways under different weather conditions are contained in Part 60 of the Civil Air Regulations. A special digest of the "C.A.R." has been prepared by the Civil Aeronautics Administration (Civil Aeronautics Bulletin No. 22).

LEGEND AND WRITTEN NOTES

DATE OF INFORMATION

Once the information on a chart has become obsolete, its further use for navigation is a definite hazard. One of the most important items on a given chart, then, is the date of the information represented. On the aeronautical charts of the United States and possessions, the date of the aeronautical information is given in large red type, in the lower margin. In general, it may be assumed that any important changes in the cultural and topographic information occurring up to that date have also been applied. Cn other aeronautical charts, separate dates are often given for the aeronautical data and for the other information shown.

A list showing the dates of latest prints of charts of the United States and possessions is included from time to time in the Weekly Notice to Airmen. By checking the date of a chart against this list, pilots may know whether they have a current chart or one that is obsolete. In any case the chart should be brought up to date by applying all "Notices to Airmen" subsequent to the date of the charted information. The pilot's own interests and the safety of the public make it imperative that obsolete charts be discarded and replaced by new editions as they are issued. The importance of this is emphasized by the following Safety Bulletin, issued by the Civil Aeronautics Board, on October 29, 1943:

KEEP UP TO DATE

"Cross-country flying is a full-time job, especially in war time. Certain airports are temporarily closed or limited in use during repairs or extensions. Others may be removed from public use by military necessity. The airways themselves have to be squeezed or bent or rerouted when restricted areas are established. And these are not matters which yield to guesswork.

"All such vital information is published in the next following three issues of the Weekly Notice to Airmen. After that all pilots and navigators are expected to be informed. That is what is meant when it is stated that pilotage these days in a full-time job. As soon as promulgated these deviations in standard procedure are sent out over the CAA teletype to all communications centers, and are posted in brief upon bulletin boards. But the temporary changes are not further publicized and there is frequently a considerable time lag before permanent changes appear on airway charts.

"Recently the realignment of the north leg of a 1adio range, made necessary by the sudden establishment of a military danger area, necessitated a reversal of the signals in the quadrants. On two occasions pilots became lost and crashed—the result of their failure to make use of the sources of vital information available to them. There is no place on the airways today for the navigator who is not up to the minute on his route information.

"The Weekly Notice and NOTAMS are the pilot's heavy reading—a MUST list—and he does well to cultivate the teletype-bulletin board habit if he aspires to grow gray in the service."

SOURCES

The sectional charts are considered as the basic charts of the United States, the smaller scale charts being largely compiled from them. In the lower left margins of the sectional charts there are listed the principal sources from which they were compiled.

The source notes are in very general terms and list only the principal agencies furnishing the material. Some of the principal sources are as follows:

Nautical charts and surveys of the U. S. Coast and Geodetic Survey;

Topographic quadrangles and surveys of the U. S. Geological Survey;

Quadrangles of the U. S. Soil Conservation Service, U. S. Army Engineers, and U. S. Mississippi River Commission;

Air photographs of the U. S. Department of Agriculture;

Forest maps of the U. S. Forest Service;

County maps of the State-wide Highway Planning series, prepared by the various States; and

Aeronautical data from the Civil Aeronautics Administration.

In addition to the above, the maps and miscellaneous publications of many other Government and commercial organizations are consulted. More than 50 separate sources are referred to, and for some charts more than a thousand source maps and photographs are used. Throughout the entire process, the goal of presenting a faithful and accurate picture of the terrain as it will appear to the airman is kept constantly in mind.

THE FLIGHT CHECK

The last and not the least important source used in the preparation of the sectional charts is the "flight check" data. The entire area covered by a new chart (or by a new edition of an old chart) is inspected from the air by a trained observer, and the details of the chart are compared with the ground below. Any corrections and improvements noted in this way are indicated on a proof copy of the chart, and applied to the printing plates before the final edition of the chart is printed. Many distinctive landmarks, which are of great value in identifying position, are added to the charts from the flight check notes.

In order to keep pace with new construction in the charted areas and to keep the charts of maximum usefulness to pilots, the program calls for new flight checks of all charts at intervals of 2 to 4 years. These flight checks also furnish the means for testing new instruments and new methods of air navigation, providing in this way a real contribution to the advancement of practical air navigation.

LEGEND

The word "legend" means "to be read," and ALL notes in the margin of the chart are there for that purpose. The principal symbols are indicated

and explained by notes. Any unusual conditions or treatment are explained.

A key to the gradient tints showing elevations on the chart is included in the legend, and also an index showing the relation of the particular chart to other aeronautical charts of the various series. The relation of the chart to international mapping indexes and geographic systems is also shown, for those who may be interested in this information.

PROJECTION

Not the least important of the written notes is the statement of the projection on which the chart is based—Lambert, Mercator, or stereographic. If (as is usually the case) the Lambert projection is used, the standard parallels should be noted. The convergence of the meridians is the same for all charts based on the same pair of standard parallels; it is different, however, for each different projection band on different standard parallels, and this is important in many problems of navigation.

SCALE

Scale is indicated on the charts in several forms. First is the written statement of the proportion existing between the chart and the portion of the earth represented thereon, as 1:500,000, or 1:1,000,000. These expressions are read as "one to five hundred thousand," and "one to one million." Sometimes they are written as fractions, as $\frac{1}{500,000}$, and are referred to as the representative fraction of the chart.

The statement that the scale is 1:500,000 means that 1 inch on the chart represents 500,000 inches on the ground; or that 1 foot, 1 yard, 1 centimeter, or any other unit, represents 500,000 of the same units on the ground.

In the borders of the charts are the graphic scales showing the number of statute miles corresponding to any given distance on the charts. On the
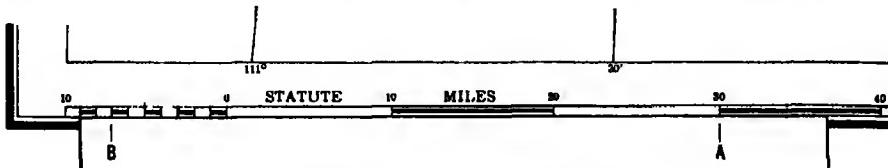
Figure 77.—Measuring distance with the graphic scale.

sectional and regional charts the scales are divided into 10-mile intervals, with an additional 10-mile interval at the beginning of the scale subdivided into single miles. In this way it is easy to measure any distance on the chart to the nearest mile, or even closer. For example, in figure 77 the distance AB between two points on the chart is found to be 37 miles.

On all but the large scale airport charts, at frequent intervals meridians and parallels have been subdivided into minutes of latitude and longi-

tude (or into multiples thereof, on the smaller scale charts). This makes it easy to determine the latitude and longitude of any point on a chart, or to plot on the chart any feature for which the latitude and longitude are known. In addition, the subdivided meridians provide a scale of nautical miles, since a minute of latitude may be considered as a nautical mile. This is true, regardless of the projection used.

THE PRACTICE OF CHART READING

The cultural features of the terrain constitute a most important class of landmarks. For example, on plate IV, compare the distinctive pattern of railroads and highways at Yakima, with that at Ellensburg. The pattern of roads, railroads, and other cultural features gives to each locality its own distinguishing marks.

The topographic features are frequently of outstanding importance in flying a course by landmarks. For example, in flying from Winchester, Va., to Washington, D. C., it is only necessary to head the airplane for the prominent notch in the Blue Ridge Mountains toward the east; Washington may be reached by continuing on approximately the same course after passing the notch. This notch is apparent on the sectional chart because of the highway passing through it, and also because of the diminished width of the contoured ridge at that point. Other typical and better known landmarks of this kind are the Delaware Water Gap, Stone Mountain, El Capitan, Sugarloaf Mountain, and so on. Such features may be readily selected from the chart by pilots experienced in chart reading and the interpretation of relief.

Often a combination of landmarks affords a most definite identification. There may be a grain elevator at a certain town, but if there are also grain elevators at a number of other towns in the same vicinity this fact loses any significance. If it can be seen from the chart, however, that the town has a grain elevator, is on a double-track railroad, and is near the fork of a river, this combination of landmarks is not likely to be duplicated within a hundred miles, and identification is quick and positive.

Often a flight can be planned so that some continuous landmark (such as a highway, railroad, pipe line, or river) lies well to one side of the route. If at any time the pilot becomes uncertain of his position, he needs only to turn toward the landmark selected and, when he has reached it, follow it toward his destination. At other times the flight can be planned so that the route lies between two converging highways, two railroads, or a combination of other landmarks, thus making certain that some definite landmark can always be found.

Some pilots prepare a table listing landmarks obtained from the chart for a given route; more often the selected landmarks and check points are marked with colored pencil on the chart itself. The important thing is to study the route in advance, to be able to select those landmarks that can most readily be identified, and to know just about when and where to look for them in flight.

QUESTIONS

1. What are the chief distinctions between a map and a chart?

2. State the various types of information to be found on an aeronautical chart.

3. What is meant by culture? topography? relief? legend?

4. How is relief indicated on aeronautical charts?

5. Why might the drainage on the ground—the size of lakes and reservoirs and the width of rivers—differ appreciably from the chart at times?

6. From the information on plate IV arrange the following cities in order of their size and importance: Easton; Wenatchee; Yakima; Ellensburg.

7. How can you distinguish on the chart between single-track railroads and those with two or more tracks?

8. What is meant by a "prominent" highway? Are secondary highways ever more prominent than main highways?

9. Why is the elevation above sea level of the top of an obstruction more important to the airman than the height of the obstruction above the surface of the ground?

10. On plate IV find at least three instances of exaggeration of scale.

11. Elevations on an aeronautical chart are given with respect to what plane of reference? Is the shore line on the chart at mean sea level, or higher, or lower?

12. What is a contour?

13. What is meant by "contour interval"?

14. On plate IV, point out the following: (a) Contours which indicate a valley, although no stream is shown; (b) a steep slope; (c) a gradual ascent.

15. What contour intervals are used on the various series of aeronautical charts?

16. If the highest contour shown on a mountain peak is 8,000 feet (on a regional chart), what should you assume as its maximum height?

17. What is the highest elevation between Yakima and Mount Rainier?

18. Estimate the elevation of Ellensburg, Cle Elum, and Tieton Reservoir.

19. What does the blue shading on Mount Rainier indicate?

20. What use might a pilot make of a CAA intermediate field?

21. Is seaplane operation over land areas safe or practical?

22. What is meant by an airport of entry? a flight strip?

23. How can you tell from the chart whether an airport has facilities for night landing?

24. Describe the system of numbering airport runways.

25. If you were instructed to land on runway 12, in what direction would you head when landing?

26. What is the significance of the site number of an intermediate field or beacon?

27. How could you distinguish in flight between a rotating airway beacon and a rotating landmark beacon?

28. Distinguish between a prohibited area, a caution area, and a danger area.

29. What is meant by magnetic variation? by compass rose? by an isogonic line?

30. Define the following: civil airway; control airport; control zone of intersection; airport traffic control tower; airway traffic control center.

31. From what sources might a pilot learn of any corrections that should be made to his chart?

32. How might he know the date of the aeronautical data on the chart? How might he tell if there is a later edition?

33. What services are performed for pilots by airway communication stations?

34. Name the principal sources of information from which aeronautical charts are compiled.

35. What is meant by a "flight check" of an aeronautical chart?

36. What is meant by the phrase "1:1,000,000" as an expression of scale?

37. On plate IV, scale the distance between Boeing Field (Seattle) and Yakima Airport; between Yakima Airport and Fancher Airport (Wenatchee).

38. Write in the blank spaces on page 100 what each of the symbols shown thereon represents.

Dome

4260

3969

①

REDMONO RADIO
Non Directional
Radio Beacon
368 RG
(50 watts or greats)

WASHINGTON

115

12°W

270°   90°   270°   90°
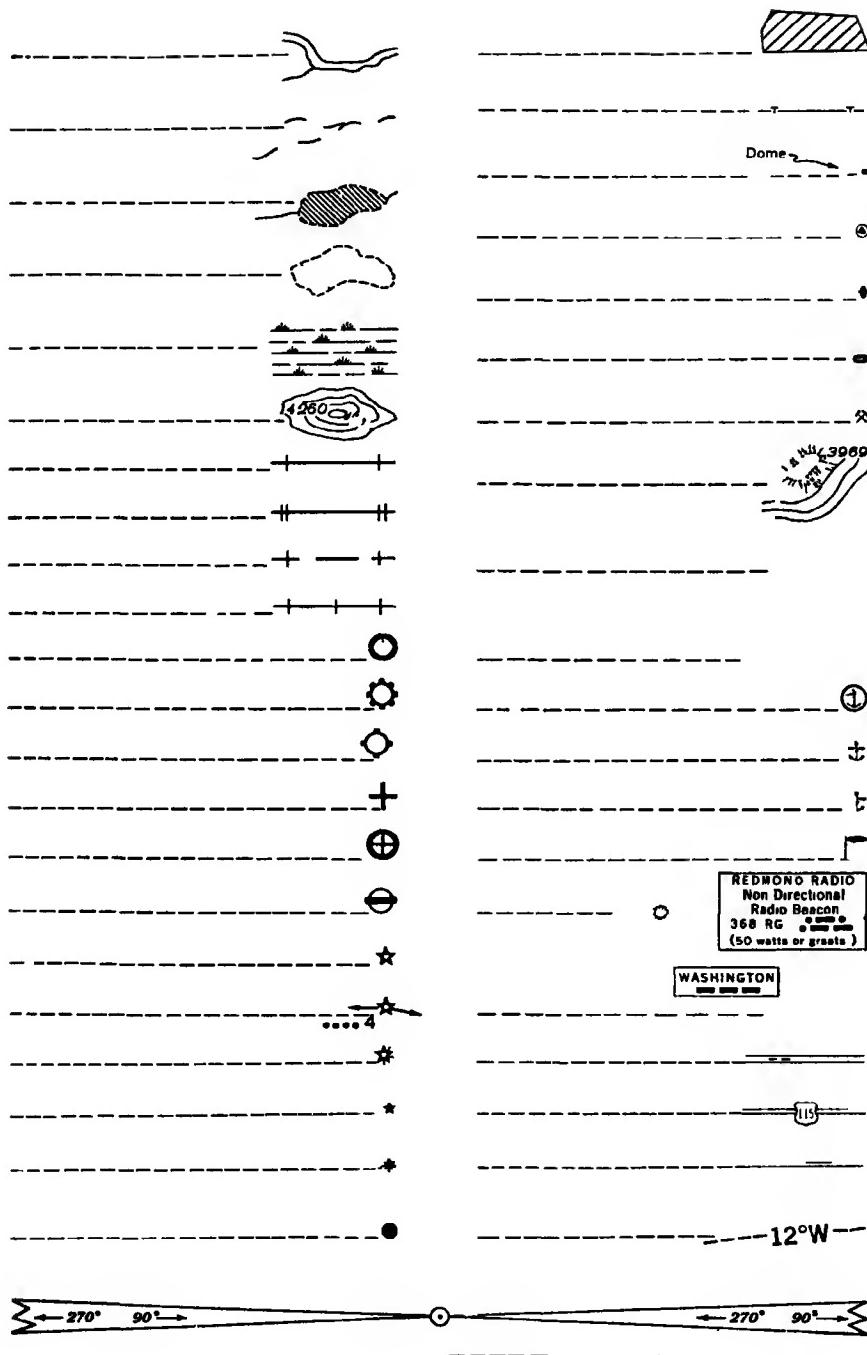
Chapter VI.—DEAD RECKONING

THE PLACE OF PILOTAGE

Under conditions of good visibility, ordinary cross-country flying may be satisfactorily accomplished by very simple methods. It is only necessary to plot on the chart the route which it is desired to follow, to note from the chart any characteristic landmarks along the route and, in flight, to direct the airplane along the route by reference to the selected landmarks.

There are other factors to be considered, of course: the route laid out must be a *safe* one, avoiding (when possible) flight over large bodies of water, high mountains, or other hazardous terrain; a field with refueling facilities must be available within safe cruising radius of the airplane, even allowing for unexpected head winds; advantage should be taken of established airways and intervening airports for emergency landings; weather conditions along the route and at the destination, as well as at the starting point, must be taken into account; the time required for the trip must be checked against the number of hours of daylight yet remaining; and, of course, the air traffic rules pertaining to contact flying must be observed at all times. These factors, however, have to do with the safe operation of the airplane, while the procedure noted above deals with flying from place to place by reference to visible landmarks which can be identified on the chart.

Flying an airplane from one place to another solely by reference to visible landmarks is known as *pilotage*.

The magnetic compass may be used to advantage, even in simple pilotage. For example, if it is seen from the chart that a road, railroad, river, or other such feature lies directly along or parallel to the route, it is only necessary to head the airplane so that its path or track is continuously over the landmark selected, and to note the compass heading required in order to do so. This is the correct heading to fly, and it should be maintained until it can be checked again in the same way.

For such use, we need not even be concerned with magnetic variation, compass deviation, or wind drift (to be discussed later); if the airplane has accurately tracked the landmark in question, all three are included in the compass heading noted, and have been correctly allowed for.

Pilotage as a separate method of navigation is of very limited usefulness. It should never be solely relied upon except for comparatively short flights of a local nature. It must be considered fundamental, however, as it is combined with any other form of navigation that may be used, if in no other way than to identify the landfall or to locate the airport of destination at the end of a flight.

ADVANTAGES OF DEAD RECKONING

When a pilot is limited to flying by landmarks alone, he loses the saving in distance of the direct air route. He also loses the satisfaction of bringing his airplane directly to the intended destination by his own knowledge of navigation. Furthermore, if the weather should close in unexpectedly during flight and the familiar landmarks could not be found, the results might be extremely serious, not only to the pilot, but to the life and property of others as well.

As already defined, dead reckoning consists of determining position by means of direction and distance from a known position. By means of dead reckoning a pilot can fly fairly close to the landmarks for which he is looking, even when his information is not very reliable. Because he knows just about when and where to look for them, he will often succeed in finding them when a pilot without such training would miss them altogether. If he has fairly accurate knowledge of his own course and speed, and of wind direction and velocity, he may proceed even under adverse weather conditions with more certainty than an untrained pilot might have in clear weather. In any event, the ability to navigate by more advanced methods is certain to result in increased safety and greater operating efficiency, and will give considerable confidence and mental satisfaction to the pilot as well.

BASIC PROBLEMS IN DEAD RECKONING

There are two basic problems in navigation by dead reckoning, one essentially the reverse of the other. In general terms they are:

Case I. When planning a flight, before taking off, to determine from the chart and weather data the distance and the compass heading to be followed between two points.

Case II. While in flight, from the indicated compass heading, air speed, and other observed data, to determine and plot on the chart the track being made good and the position of the airplane along the track at any time.

These two problems are not mutually exclusive, but are usually carried on almost continuously, side by side. Before taking off, the pilot estimates his compass heading and ground speed from known data and predicted winds (Case I); almost as soon as he is in the air he begins to check his instruments in order to determine his actual track and ground speed (Case II). If the data determined in flight differ from his preflight predictions, he must revise his original estimates accordingly (Case I), then begin again to check the results by observation and the indications of his instruments—a process which must continue until his destination is in sight.

CASE I

In order to determine the compass headings to be followed, five steps are necessary:

1. **Plot on the charts the intended track, either as a** straight line or as a series of straight lines.

2. **Measure the true course,** or courses, on the chart.

3. **Find the true heading,** by making allowance for the effect of wind.

4. **Find the magnetic heading** by allowing for magnetic variation; and

5. **Find the compass heading,** by allowing for compass deviation.

The true course and the magnetic variation (steps 1, 2, and 4) are obtained from the chart; wind information (step 3) is normally obtained from the Weather Bureau station at the airport; and compass deviation (step 5) is obtained from the deviation card made out for the particular compass to be used in flight, which is posted in the airplane. Since the information for the five steps is to be obtained at three different times and places, it is essential that some form be used for recording the data as received. Figure 78 shows a portion of a form that has been found very satisfactory for this purpose.

											FLIGHT
Leg No	Ck point No	FROM	TO	TC	WC	TH	VAR	MH	DEV	CH	Lo d la

Figure 78 - Portion of form for flight data.

In order to avoid confusion, the abbreviations in the above form are explained and briefly defined at this point. Definitions will be discussed in fuller detail in the portions of the text where the various items are treated. Figure 95 provides graphic definitions of these and other terms.

TC = True Course, measured on the chart.

WC = Wind Correction Angle, applied to offset the effect of wind.

TH = True Heading = TC plus or minus WC.

Var = Magnetic variation, taken from the chart.

MH = Magnetic Heading = TH plus or minus Var.

Dev = Compass Deviation, taken from the deviation card of the compass to be used for a particular flight.

CH = Compass Heading = MH plus or minus Dev.

"Ck. point," in column 2 of the form, means "check point."

In drawing wind triangles to determine the effect of wind and the correct allowance to be made for it, some standard system of lettering is desirable. If such a system is adopted, the same letters will always represent the same thing (for example, *EW* may always represent the wind direction and velocity), and the possibility of error is reduced. The following system has been rather widely used, and is therefore recommended with the hope that its use may become general. The only difference from previous usage is that in the system here recommended the use of an arrow

to represent the *direction* of a given force, such as wind direction, is omitted. In previous usage this has been written as $E \rightarrow W$; as recommended here, it should be written simply as EW. The order in which the letters are written always indicates the direction of force or motion: $EW =$ direction from E to W; $WE =$ direction from W to E. This affords much greater simplicity both in printing and in the lettering of problems in navigation. The recommended system of lettering is as follows:

E $=$ Earth; that *point* on the earth from which the airplane takes off.
W $=$ Wind; end of wind vector for 1 hour.
P $=$ Plane's position at the end of 1 hour.

Then, always:

EW $=$ Wind vector.
WP $=$ True heading and air speed.
EP $=$ True course or track, and ground speed.

These terms and relations will become clear as they are used in the succeeding sections.

1. TO PLOT THE INTENDED TRACK

The sectional and regional charts may be considered as flight charts, in contrast with the planning charts, which are intended primarily for ground study. When the starting point and destination fall within the limits of a single flight chart, it is only necessary to draw a straight line between them. The straight-line route should then be studied, and any desirable modifications made in order to take advantage of the facilities afforded by the civil airways, or of outstanding landmarks and check points, or to avoid hazardous terrain.

When starting point and destination do not fall within a single chart, the nature of the Lambert projection is such that any desired number of charts can be joined together and the straight line drawn between the two points across all the charts involved—provided one can find a table or floor large enough, and a straightedge long enough. A far better and more convenient procedure, however, is to plot the route first of all on a small scale planning chart. Any major modification that may be necessary can usually be made on the planning chart, and the route transferred to the flight chart may often be regarded as final.

A number of the meridians and parallels on the United States planning chart are subdivided into 10-minute intervals. This makes it easy to determine the latitude and longitude of the point at which a route enters a sectional chart. If it crosses the entire chart, and a long straightedge is available, all that is necessary is to draw a straight line between the points where the route enters and leaves the chart. If the long straightedge is not available, the latitudes and longitudes of several other points along the route are also transferred, and the route is plotted on the flight charts as a series of short straight lines between these points.

An alternate procedure, if a long straightedge is not available, is to use a protractor as illustrated in figure 79. This protractor was specially

designed for use with the aeronautical charts of the Coast and Geodetic Survey, on the Lambert projection. It may also be used as a parallel ruler, and contains scales of statute miles for both the sectional charts (1:500,000), and the regional charts (1:1,000,000); the scale of miles for the sectional series is equally suitable for the planning charts,

Figure 79.—Protractor used as a long straightedge.

(1:5,000,000), since they are exactly one-tenth the scale of the sectional charts. If a long straight line is desired as between A and B in the figure, a thread may be inserted in the hole at the center of the protractor; then with one end of the straightedge of the protractor at A, the thread is stretched to pass through the point B; the other end of the straightedge is caused to line up with the thread and the line AC is drawn. The operation is then reversed with the straightedge at B and the thread passing through A, and another section of the line is drawn; any center sections may be drawn in the same way, and the long straight line completed. This can be done more quickly and easily than it can be described.

In the absence of other equipment, the edge of a chart may be made to serve as a straightedge. Often even the edge of the same chart on which the route is to be drawn can be folded back and used in this way.

2. TO MEASURE THE TRUE COURSE

The true course may be defined as the angle between the plotted course line and the selected true geographic meridian printed on the chart. It is always measured in a clockwise direction from 0° at true north up to 360°. In navigation it has become customary to express all courses in 3-figure numbers: thus, true north is 000°, north-northeast is 022°30′, northeast is 045°, west is 270°, and north may also be expressed (for some problems) as 360°. Pilots should drill themselves in the "360° system" until they can visualize instantly the direction corresponding to any given number of degrees—an exercise known as "boxing the compass."

As explained on page 45 and illustrated in figure 35, the true course should be measured with the meridian nearest halfway between the starting point and destination. The method of measurement, using a common type of protractor, is further illustrated in figure 80.

The foregoing rule holds true, and the entire distance may be flown as one course, when the two points are separated by not more than 3° or 4° of longitude. When the difference of longitude between the two points is more than 3° or 4° the straight line on the chart should be divided into sections crossing not more than 3° or 4° of longitude each, and the true course to be flown for each section should be measured with the middle meridian of that section.
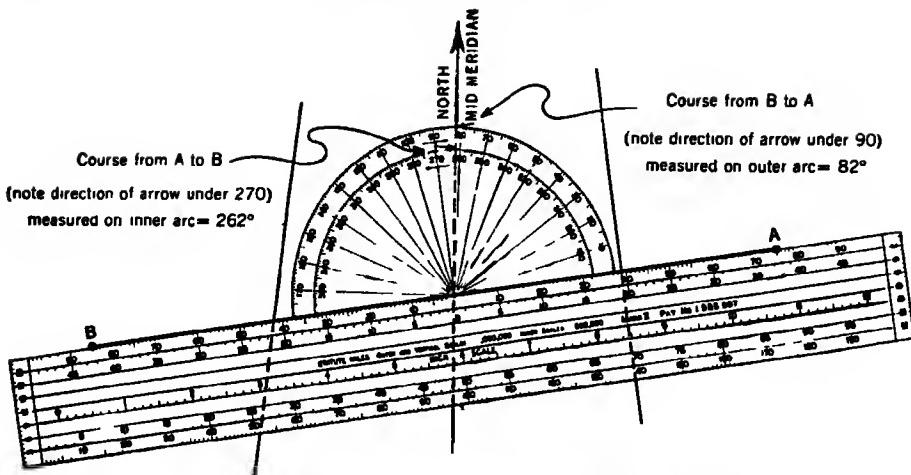
Figure 80.—Measuring the true course with a common type of protractor.

For example, figure 81 illustrates the method of determining the series of true courses to be flown between St. Louis and Minot.

The distance is 863 miles, and the difference of longitude is nearly 12°, which is too great to be flown satisfactorily in one course. The route is
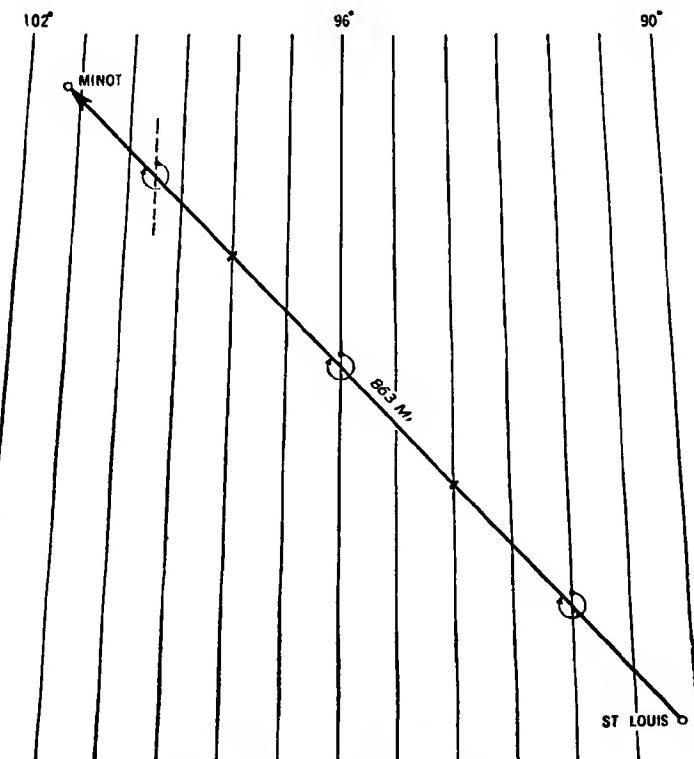
Figure 81.—Subdividing a long route.

therefore divided into three sections crossing approximately 4° of longitude each. The true course to be flown throughout the total length of each section should be measured with the middle meridian of that section, and the course should be changed in flight as the end of each succeeding section is reached. This method makes it possible to fly the great circle route by a series of short courses (rhumb lines).

Except in large airplanes with provision for a separate navigator, it is usually impossible to do much, if any, plotting or drawing while in flight. Instead, any routes or alternate routes that might possibly be required should be plotted before leaving the ground, and the data noted on the chart.

If the course for only the initial section of a route is known, the course for other sections may be determined without measurement, by applying a correction for the convergence between the two meridians in question.

For flight in an easterly direction, add the correction for convergence;
For flight toward the west, subtract it.

The foregoing rule may also be expressed as follows: If the PLANE is WEST of the meridian where course measurement is desired, ADD the correction. The rule may be easily remembered from the familiar initials "PWA."

Illustrating this procedure, suppose that the course for the first section of the St. Louis-Minot flight (fig. 81) is known, having been measured at the 92nd meridian. The course for the second section is to be determined at the 96th meridian, the difference of longitude between these two meridians being 4°. The convergence corresponding to a difference of longitude of 4° is subtracted from the course for section 1. Table 3, p. 47, shows the convergence per degree of longitude for each of the projection bands now available (1945). By reference to the table, the correction to be subtracted in this case is found to be approximately 2°4 (4 × 0°6). Whenever possible, however, it is better practice to measure the true course than to calculate it by any method.

If some entirely new and unforeseen route must be adopted after beginning a flight, there is little opportunity to do more than estimate the course angle. In such a case a nearby compass rose on the chart may be of assistance in making an accurate estimate.

3. TO FIND THE TRUE HEADING

The airplane may be headed directly toward its destination only in still air, or with the wind parallel to the course (head wind or tail wind). In practice, these conditions are not often met, and the airplane must be headed somewhat into the wind, in order to compensate for the effect of wind and to track the desired true course plotted on the chart.

In order to make the necessary allowance for the effect of wind, and to find the true heading from the true course, the action of the wind upon an aircraft must be fully understood. The distinctions made in the following definitions should be thoroughly learned and strictly adhered to at all times.

The **true course** is the direction of intended flight. It has already been defined as the angle between the course line plotted on the chart and the meridian nearest halfway between the extremities of that line.

The **true heading** is the true course plus or minus any necessary allowance for the effect of wind.

Air speed is the speed of the airplane with respect to the air, and is the speed registered by the air speed indicator (when corrected for altitude, temperature, and installation error).

Ground speed is the speed of the airplane with respect to the ground, and is the resultant of the heading and air speed of the airplane and the direction and velocity of the wind.

The **drift angle** is the angle between the true heading of an aircraft and its track or flight path over the ground.

The **wind correction angle** is the angle, with respect to the true course, at which the airplane must be headed into the wind in order to counteract exactly the effect of wind, and to make good the intended track or true course over the ground. When the wind correction angle has been accurately determined and applied, the true course and the track are identical. Under other conditions, the track will differ from the true course.
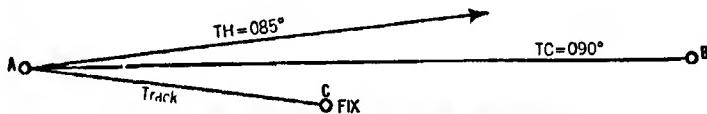
Figure 82.—Relation between true course, true heading, and track (under-correction).

The true course, true heading, and track are further illustrated in figures 82 and 83. In both cases the true course is 090°; to compensate for a northerly wind, in figure 82 a true heading of 085° was adopted. This proved to be insufficient, however, and later a fix was obtained south of the true course, at C. The line AC represents the actual track over the ground. In figure 83 a true heading of 080° was adopted, but this allowance proved to be excessive when a fix was obtained at D. In this case, the line AD is the track.
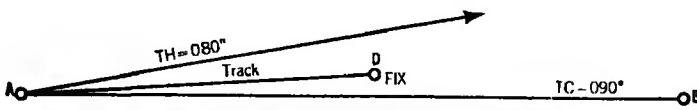
Figure 83.—Relation between true course, true heading, and track (over-correction).

The **track** may be defined, then, as the actual flight path of an aircraft over the ground.

Also, when the allowance for wind has been accurately made, the drift angle observed in flight will be equal to the wind correction angle. This *must* be true if the airplane is to track the true course as planned.

One of the best illustrations of the effect of wind upon an aircraft in flight is found in the old catch question about the toy balloon. While in flight, a pilot sighted a toy balloon directly over a church steeple. He

continued on his way for 15 minutes, then reversed his course and turned back to see if he could again find the drifting balloon. It was sighted over a point which he knew from his chart was 7 miles south of the steeple. The problem was to determine the wind direction and velocity from this information.

At first, the data seem insufficient. On further consideration, it is realized that the airplane drifts with the wind in exactly the same direction and amount as the balloon. Disregarding the surface of the earth, and considering only relationships in the air, it is as though the balloon were motionless in a sea of air, since it moves with it and as a part of it. The distance in the air between the airplane and the balloon is unchanged by anything except the air speed of the airplane itself. If the pilot flew away from the balloon for 15 minutes, regardless of the direction, it will also take him 15 minutes to return. Thirty minutes will have passed, therefore, between the sighting of the balloon over the steeple and sighting it again 7 miles south, and the wind can be determined as 14 mph, from the north. In exactly the same way, an airplane in flight is subject to the full effect of the wind, even though the airplane may be moving under its own power in an entirely different direction.

For example, an airplane headed due east from E (fig. 84) flying at an air speed of 100 mph should reach D (100 miles distant) in 1 hour; but, during the hour of flight the plane has also been subject to the full effect of a wind EW of 20 miles per hour, from 315°. Since
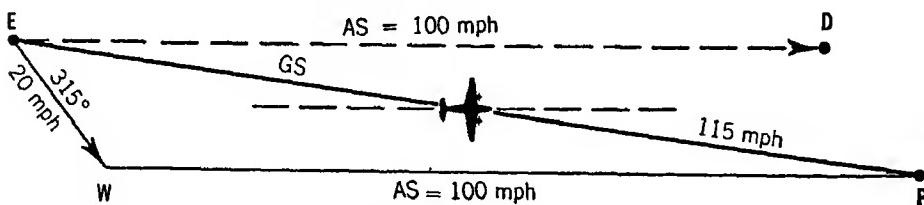
Figure 84.—Wind drift.

the airplane is subject to the full effect of both the wind and its own motion, let us assume that for 1 hour it ceased flying, and floated with the wind, like a balloon, from E to W; then for the next hour the wind ceased to blow and the airplane flew without hindrance from W to P. Of course, no such truce could be worked out, and both effects took place at the same time, with the airplane arriving at the end of 1 hour at P. The line EP represents the track followed by the airplane over the ground; if the length of EP is measured by the same scale with which the other distances were laid off, we may determine also the speed the airplane has made over the ground in passing from E to P, or 115 mph.

Note that, in accordance with the standard system of lettering given on page 104, in figure 84:

EW = wind vector
WP = true heading and air speed, and
EP = track and ground speed.

Figure 84 illustrates what would happen if a pilot followed a compass course without regard for wind effect. Under the conditions shown, the airplane would pass well south of and beyond its objective. Figure 85 is the same as figure 84, except that emphasis in this case is upon the
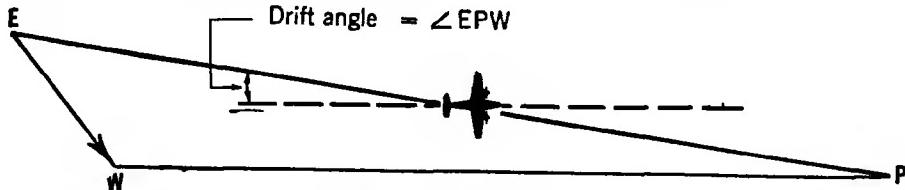
Figure 85.—The drift angle.

drift angle. By simple geometry it is apparent that the angle EPW is equal to the drift angle, as it would be observed at the airplane, and in practice it is usually so considered.

In order to proceed directly toward the destination, the airplane must be headed into the wind at such an angle that the effect of the wind is exactly counteracted; if this is done correctly the plane will be over the intended track throughout the flight. This angle (the wind correction angle) can be determined graphically when the wind direction and velocity are known, as follows:

The true course from E to a distant point, D (fig. 86) is found to be 090°, or due east. From the point of departure, E, on any convenient scale lay off EW to represent the direction and velocity of the wind. From W, with radius equal to the air speed of the airplane draw an arc intersecting the intended track at P. In the figure, $EW = $ wind direction and
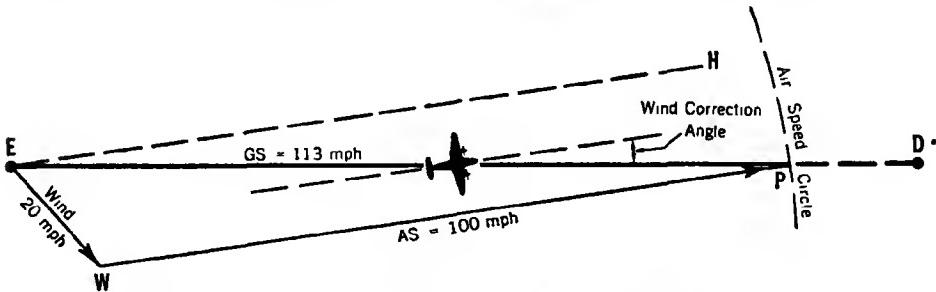
Figure 86.— Correction to course for wind, and determination of ground speed.

velocity; $WP = $ air speed of plane; and the wind correction angle $=$ angle EPW. This angle may be measured with a protractor and applied to the true course in order to obtain the true heading WP. The fact that WP represents the true heading to be flown may be visualized more clearly if EH is drawn parallel and equal to WP.

EP is measured and found to represent 113 mph, the ground speed along the route; from the ground speed, the exact flying time between E and D can be obtained.

It must be remembered that wind directions given in weather reports are *true* directions. In constructing any wind triangle, it is the true course that should always be plotted, since both directions must be in the same terms.

Referring again to figure 86, it has been stated that the angle *EPW* is the wind correction angle. It is also the drift angle that will be observed in flight as long as the airplane is headed in the direction *WP* and there is no material change in wind. This constitutes a valuable check, enabling the pilot while in flight to determine easily if the wind conditions being met are in accordance with those predicted.

Winds vary with time, place, and altitude, and the conditions experienced in flight may differ considerably from those indicated in weather reports and forecasts. One probable cause of changing conditions may often be eliminated by maintaining a constant altitude. Whenever an appreciably different drift angle is observed, it is a warning that wind conditions have changed and revised corrections must be determined and applied. Practically all methods of determining ground speed are based on the assumption of constant air speed, which in turn is based on the assumption of level flight. Quite obviously, the forward speed over the ground is materially affected when climbing or descending, and allowance for any such periods should be made when determining the position along the intended track.

Figure 87 illustrates the application of the allowance, or correction, for wind effect under varying conditions. For any particular case it is believed that a rough sketch similar to one of those in the figure will re-
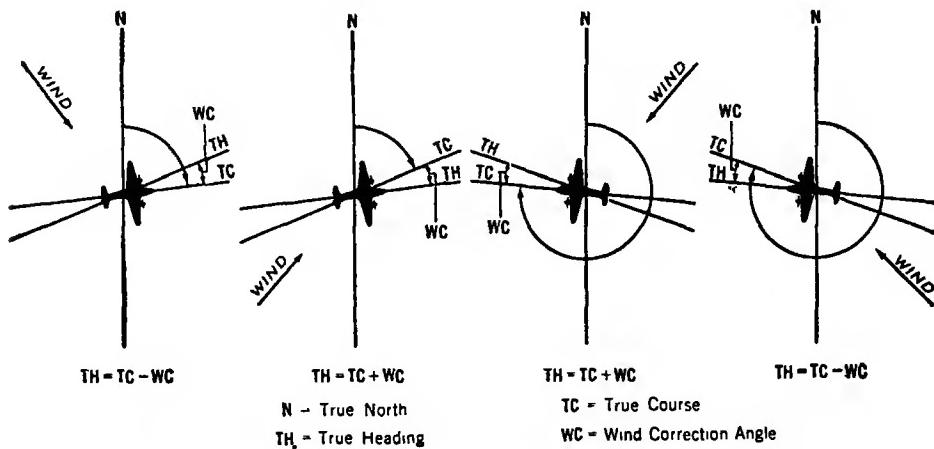
Figure 87.—Combining true course and wind correction to find the true heading.

move any doubt the pilot may have as to whether the allowance for wind should be added or subtracted.

By comparing the various parts of figure 87 we can formulate this general rule: For wind from the right, add the correction; for wind from the left, subtract. This may be remembered more readily if we make the

rule read, ADD WIND RIGHT—and, of course, we would not wish to add wrong!

From the rule just stated, and also from a study of figure 87, it should be apparent that if a pilot wishes to reverse his direction of flight, and retrace his course, he must reverse the correction for wind. If 5° were added to the true course to compensate for drift on the original heading, 5° must be subtracted from the course after turning back.

To illustrate, in figure 88 suppose that it is desired to fly an aircraft due west (true course = 270°) and that a northerly wind requires an allowance of + 5° (wind from right) to compensate for drift. The true
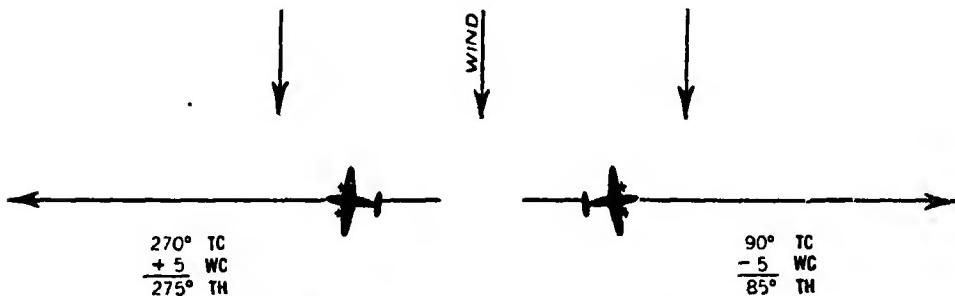
Figure 88 —Wind correction angle reversed for opposite courses.

heading then is 275°. For the return trip the true course is 090°, and the wind correction angle (which remains the same unless the wind has changed) must be subtracted: 090° — 5° = 085°.

There are other methods of obtaining the true heading, wind correction angle, and ground speed, when the wind direction and velocity and the desired true course and air speed are known. The graphic method of constructing a wind triangle is the one foundation on which all others rest; it must be thoroughly understood if error is not to result when the other methods are used.

4. TO FIND THE MAGNETIC HEADING

As explained above, the true course is measured with reference to a true meridian printed on the chart, or true north; however, magnetic compasses are used in air navigation, and these instruments, of course, refer all directions to magnetic north. In most localities magnetic north does not coincide with true north; the angular difference between true north and magnetic north at any place is known in air navigation as the **magnetic variation** of the place.[*] It is called westerly variation or easterly variation, depending upon whether magnetic north lies to the west or to the east of true north.

Figure 89 shows the lines of equal magnetic variation in the United States for 1945, at intervals of 5°. These lines, which are also known as

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[*] It is also known as variation of the compass, or simply variation. In engineering and scientific work, variation is known as magnetic declination. but the term "variation" has been used at sea for many years, and this usage has been continued in air navigation.

isogonic lines, are shown on the aeronautical charts for each degree of variation, and in a few cases for each half degree.

On the aeronautical charts isogonic lines are shown in considerable detail. Irregularities in magnetic variation probably do not extend to flight levels above a few thousand feet, but the detailed information may be of value in various ground activities.

At all points along any given isogonic line, the magnetic variation is the same in direction and amount. Referring to figure 89, it may be seen
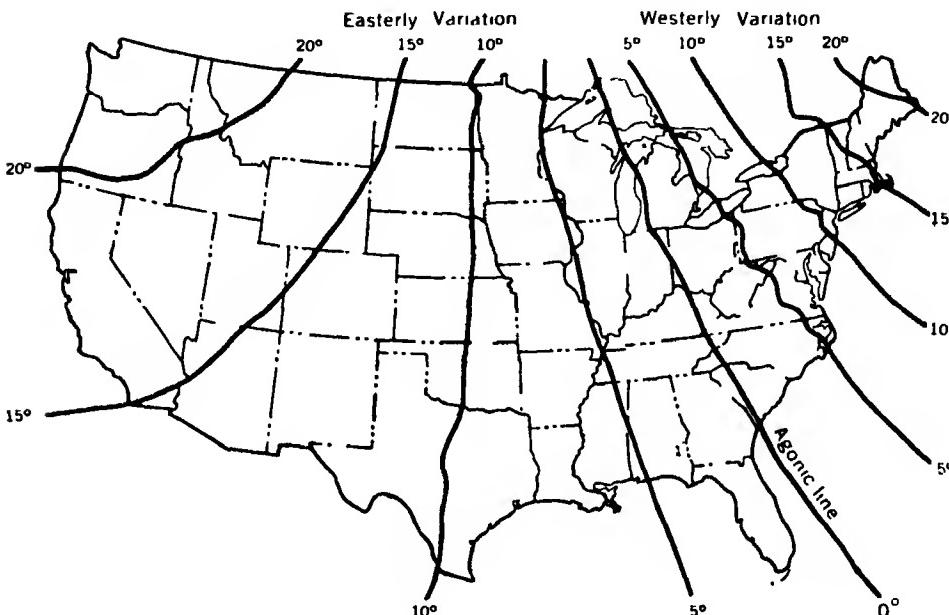
Figure 89. - Magnetic variation in the United States (1945).

that in the northeastern part of the United States the magnetic compass points west of true north (that is, the variation is westerly); in the southern and western part of the country the magnetic compass points east of true north (easterly variation). The dividing line between these two areas of opposite variation, that is, the line of 0° variation, is known as the agonic line. At all points along the line the direction of magnetic north and true north are the same. Minor bends and turns in the isogonic lines are chiefly the result of local irregularities.

When a course or heading is referred to magnetic north rather than true north, it is known as a magnetic course or heading.

A magnetic heading has no importance of its own to a pilot; it is simply a necessary step in converting a true heading to a compass heading, and as such must have some name for reference. It may be defined further as the true heading plus or minus magnetic variation.

There is no other single item in the whole field of navigation as important as the proper application of magnetic variation. Ships have been

piled on the rocks, and airplanes have crashed into the sides of mountains or have been completely lost because of misapplication of this item.

For our present problem just one rule is necessary, but it should be learned so thoroughly that a wrong application is impossible. To convert a true heading into a magnetic heading, **ADD WESTERLY VARIATION.**

Numerous rhymes and jingles have been contrived to help navigators remember this rule, but often the rhymes have proved more confusing and harder to remember than the rule itself. It is believed that if the pilot can fix in his mind the relation pictured in figure 90, there will never be any question as to the correct application of magnetic variation.
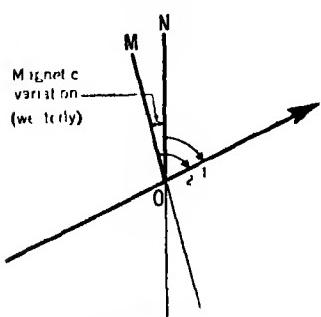
Figure 90 Magnetic variation.

In figure 90, *N* represents the true geographic meridian, and angle *1* is the desired true direction.

M represents the direction of magnetic north in the vicinity of *O* and is west of true north as indicated.

Angle *NOM* is the magnetic variation, which is westerly.

Obviously, when magnetic north lies to the west of true north, the angle *NOM* must be added to the true direction (angle *1*) to obtain the magnetic direction (angle *2*).

If westerly variation is to be added, easterly variation must be subtracted; but if we can always remember the rule, **ADD WESTERLY VARIATION,** there will never be any danger of an erroneous treatment.

The application of magnetic variation may be further clarified by two specific illustrations:

Near Portland, Oregon, the variation is about 22° east, resulting in the condition shown in figure 91. Note that in this case the magnetic compass reading is everywhere 22° less than the corresponding true direction.

Near Portland, Maine, the variation is about 17° west, as in figure 92, the magnetic compass reading being 17° greater than the true for any chosen course.

After dividing the route into sections of practical length and determining the series of true courses, as already outlined, the wind correction angles are determined and entered in their proper places in a form such as figure 78, and the true headings are obtained. The average magnetic variation for each section is then noted on the form and the true headings are converted to magnetic headings.

If this procedure is disregarded and a long route is flown in one mean magnetic heading, considerable departure from the intended track may result. For example, figure 93 shows the conditions actually existing in 1945 along the Canadian border between longitudes 90° and 96°, a distance of 273 miles. The true course for the route from *O* to *C* is 270°; the magnetic direction at the point *O* is 268°, while the mean magnetic course for the route as a whole is 264°. If a heading is flown such as to

True Compass Card

Magnetic Compass Card

Figure 92.—At Portland, Maine, magnetic variation is about 17° west, and the magnetic compass reading is 17° greater than the true for any chosen course.
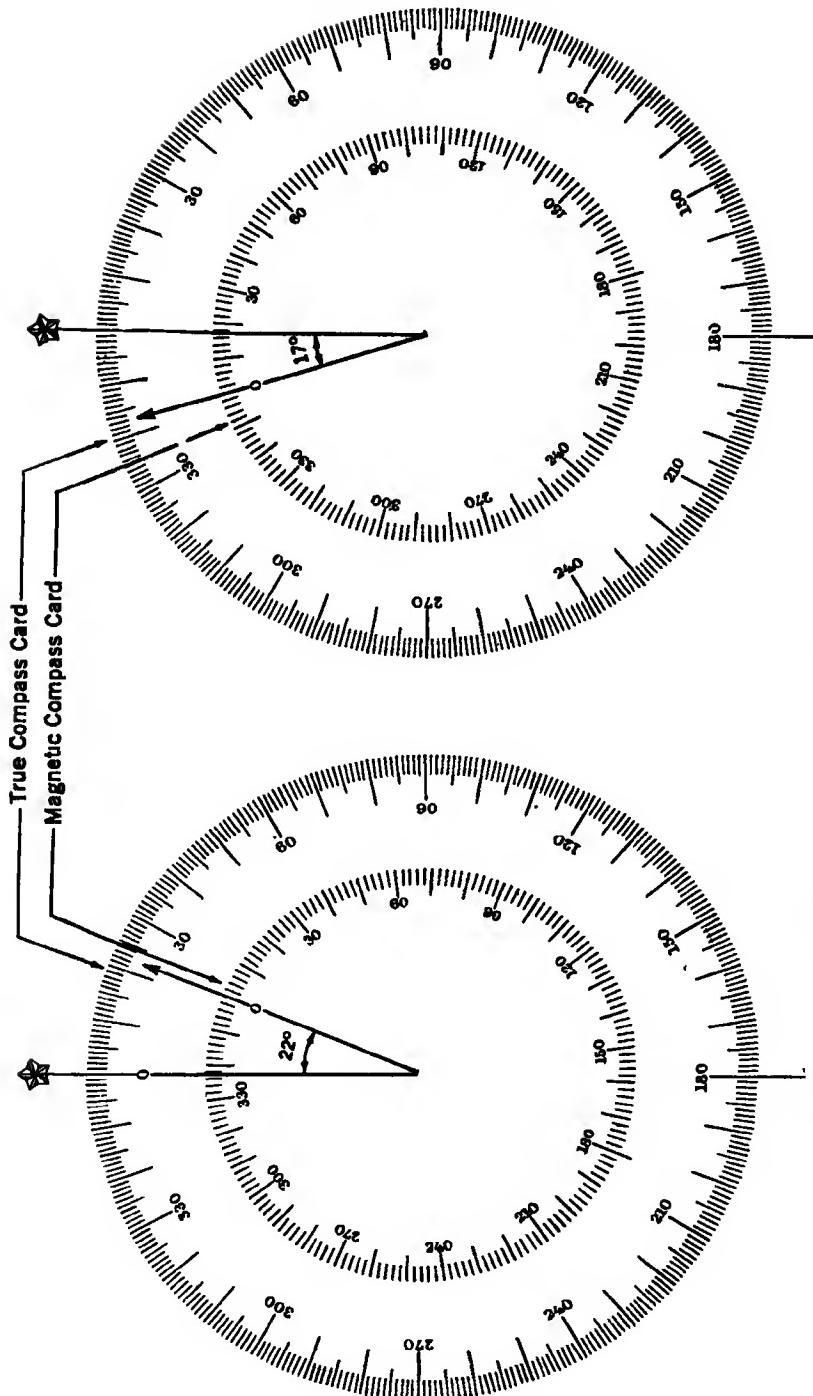
Figure 91.—At Portland, Oregon, magnetic variation is about 22° east, and the magnetic compass reading is 22° less than the true for any chosen course.

make good this mean magnetic course for the entire distance, beginning at O the course is in error by about 4°, and the plane will track the broken line south of the parallel. At the center of the route the track will be 4.1 miles south of the parallel, gradually returning to meet it at C. These conditions are typical for the northeast quarter of the United States, the
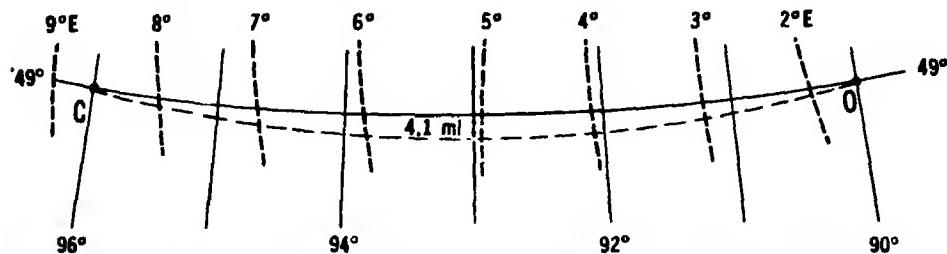
Figure 93.—Departure from intended track due to flying a mean magnetic heading.

departure from this cause being greatest, of course, where the greatest differences in magnetic variation occur.

5. TO FIND THE COMPASS HEADING

As already stated, magnetic attractions in the airplane itself (metal parts, ignition system, electric lights, placing of tools or cargo, etc.) affect the compass so that on most headings it fails to indicate correctly the directions with respect to magnetic north—that is, compass north differs in direction from magnetic north.

The angular difference between magnetic north and the north indication of the compass on any particular heading of the aircraft is known as the **compass deviation** for that heading.

Deviation differs in magnitude and direction as the airplane is pointed on different headings; it also differs for each compass, and even for each new location of a compass in the same airplane. Like magnetic variation, deviation is known as westerly, or easterly, according as compass north is west of, or east of magnetic north. As pointed out on p. 67, however, when using a deviation card such as those of figures 54 and 55, the *direction* of deviation may be neglected: knowing the magnetic heading, the required compass heading is read directly from the deviation card.

When a course or heading is referred to **compass north** rather than **true north or magnetic north, it is known as a compass course or heading.**

The compass heading is the final goal toward which the four preceding steps have been directed. It is the direction actually indicated (or to be indicated) by the compass during flight in order to reach the airport of destination. It may be further defined as the **true heading plus or minus magnetic variation and compass deviation.**

By proper adjustments, deviation on the various headings may be greatly reduced, but a reduction of the deviation is less important than knowing exactly the amount of deviation on the respective headings. Some pilots, when they have reduced deviation errors to a maximum of 2° or 3°, ignore this correction altogether, feeling that the uncertainties and varia-

tions of wind alone are likely to produce greater errors. While this may be satisfactory under some conditions, it is not good navigation and is not recommended. The fact that some errors must be present in a problem is no justification for introducing another; in fact, the more uncertainties

westerly variation westerly deviation	westerly variation easterly deviation	easterly variation easterly deviation	easterly variation westerly deviation
CH = TH + Var + Dev	CH = TH + Var − Dev	CH = TH − Var − Dev	CH = TH − Var + Dev

N = True North   TH = True Heading
M = Magnetic North   Var = Variation
C = Compass North   Dev = Deviation
CH = Compass Heading
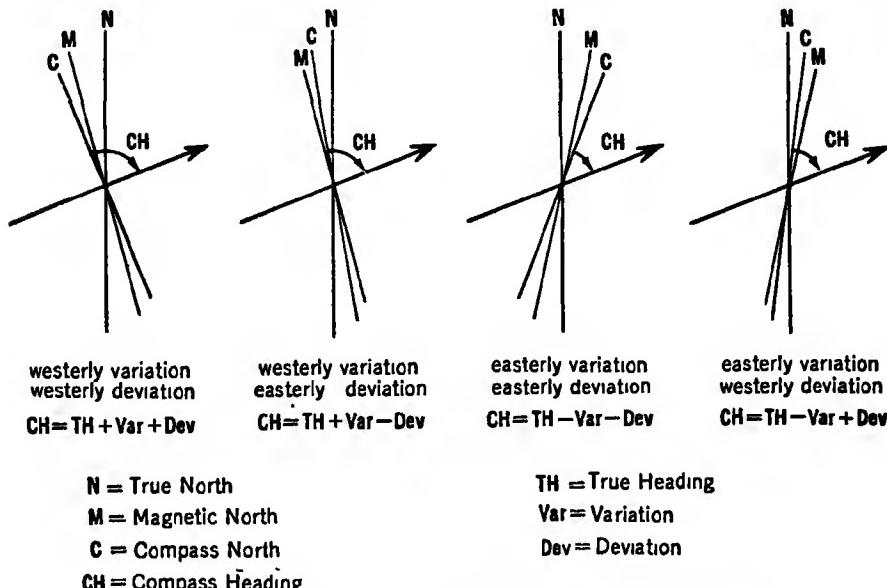
Figure 94. Applying variation and deviation to find the compass heading.

involved, the greater is the need for accuracy in the other factors, lest the errors become additive and of excessive magnitude.

N = True North (geographic meridian)
M = Magnetic North
C = Compass North
angle NOM = Magnetic Variation (westerly)
angle MOC = Compass deviation on this heading (westerly)
angle 1 = True Course
angle 2 = True Heading
angle 3 = Magnetic Heading
angle 4 = Compass Heading
AB = Track (or intended track)
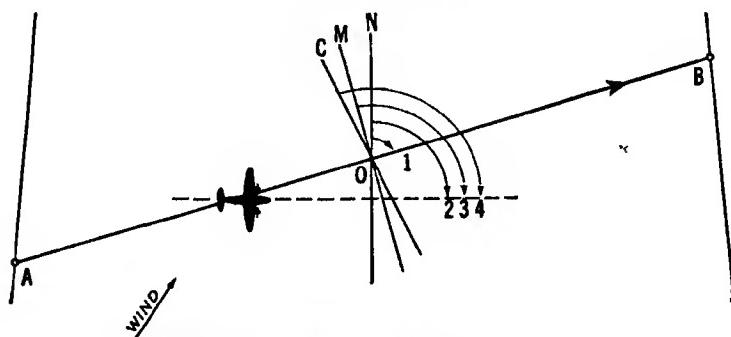
Figure 95.—Graphic definition of terms used in dead reckoning.

If the compass heading to make good the desired track works out as 133°, an effort should be made to steer that heading, and not to round it off to 135° because the compass is (often) only graduated in 5° intervals.

If deviation is to be considered as *easterly* and *westerly*, the correction becomes exactly similar to the correction for magnetic variation, and we need change only one word in our rule: **ADD WESTERLY DEVIATION.**

As with magnetic variation, it is obvious that if westerly deviation is to be added, easterly deviation must be subtracted.

Figure 94 illustrates the conversion of the true heading for different conditions of variation and deviation.

By way of summary, figure 95 affords a graphic definition of the terms commonly used in navigation by dead reckoning, and of their inter-relation.

CASE II

In the preceding discussion there has been considered only the first of the two cases of dead reckoning; namely, determining from the chart and other data available when planning a flight, before taking off, the distance, the ground speed, and the compass heading to be followed.

The second case is concerned with determining and plotting on the chart while in flight, from the observed compass heading and other instrumental data, the track being made good and the position of the airplane along the track at any time. As already pointed out, plotting and drawing in the air are scarcely practical, except in larger airplanes with facilities for a separate navigator.

The pilot-navigator of a light airplane will normally have to content himself with plotting, before he begins his flight, the route lines, courses, and distances he may need in order to spot his position by estimate. With a little practice it will be found that most of the estimates required are simple enough to be taken care of by mental arithmetic, without drawing. With a little preparation in advance, they can also be obtained from a good computer by inspection.

It may seem that the plotting of the airplane's track and position in the air should never be necessary if the course is properly determined before beginning the flight; however, wide departures from the charted route are altogether possible, intentionally or otherwise. In this event it may happen that after leaving a certain position the only data which can be obtained are (1) the compass heading (2) the wind information, and (3) the elapsed time.

Essentially, this problem is the reverse of the first. In Case I, we start with the true course measured on the chart and apply an allowance for wind effect, variation, and deviation, in order to obtain the compass heading. In Case II, starting with the compass heading observed in flight, all these factors are included and must be taken away in order to obtain the true course to be plotted on the chart. Obviously, then, all the rules of Case I must be reversed: Whatever would have been added then must be

subtracted now, and vice versa. This process of "taking away" may be called **rectifying**. As in Case I, five steps are necessary. The first consists simply of recording the compass heading being flown; the remaining four are as follows:

1. Find the magnetic heading (magnetic direction in which the airplane is pointed) by rectifying the compass heading for deviation.

2. Find the true heading (true direction in which the airplane is pointed) by rectifying the magnetic heading for variation.

3. Find the true course (track) being made good over the ground, by · rectifying the true heading for wind.

4. Plot the true course on the chart, using the same procedure outlined for measuring a course.

1. TO FIND THE MAGNETIC HEADING

If we remember the rule laid down that to convert a magnetic heading to a compass heading **under Case I we ADD WESTERLY DEVIATION**, it is evident that to rectify the compass heading for deviation we must reverse the process and subtract westerly deviation; easterly deviation, of course, should be added.

As in Case I, it is probably simpler not to think of deviation as either easterly or westerly, and to obtain from the deviation card (figs. 54 and 55), by inspection, the magnetic heading corresponding to the compass heading being flown.

2. TO FIND THE TRUE HEADING

As with deviation, we must reverse the rule of Case I, subtracting westerly variation and adding easterly variation in order to find the true heading.

As between adding in Case I, and subtracting in Case II, it may help to remember that problem one, finding the compass heading from the chart, is normally the first and basic operation, and for **Case I we must ADD WESTERLY** variation or deviation. For the second operation, performed in the air, we simply reverse the procedure.

3. TO FIND THE TRUE COURSE MADE GOOD

When the drift angle can be obtained, the true heading of the airplane may be rectified for wind, and the true course found, simply by adding or subtracting the drift angle.

Figure 96 illustrates the rectifying of the true heading for wind under varying conditions. By comparing the various parts of the figure, we see that here, again, we **reverse the rule of Case I**, and subtract the drift angle for wind from the right.

When drift observations are not possible because of adverse weather conditions, the true heading is rectified for wind by means of a wind

triangle, or other similar means, using the wind direction and velocity as given in weather reports or as last known.

$$TC = TH + D \qquad TC = TH - D \qquad TC = TH - D \qquad TC = TH + D$$

N = True North   TH = True Heading

TC = True Course   D = Drift Angle
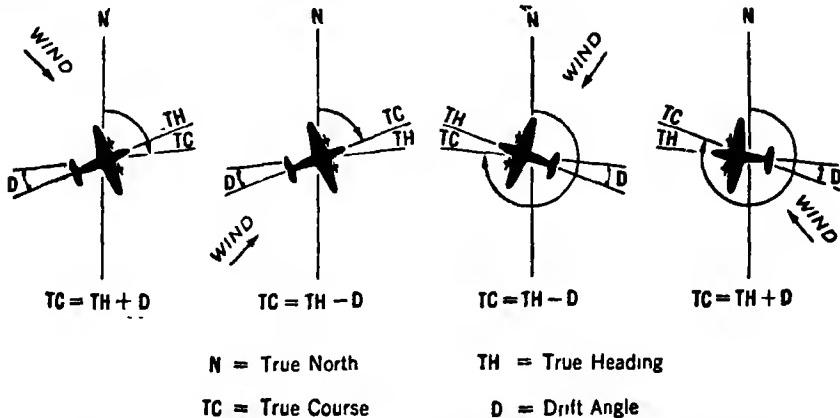
Figure 96.—Combining the true heading and drift to find the track (true course made good).

4. TO PLOT THE TRUE COURSE ON THE CHART

Having obtained the true course (track) from the three preceding steps, there remains only the problem of plotting it on the chart. For distances no greater than about 100 miles in an east-west direction (in the United States), the course may be plotted at the meridian of the last known position with a course error of about 1°; for 175 miles east-west the error will be approximately 2°, always toward the equator from the true position. Under some conditions this may be sufficiently exact; for the more precise results generally desired, we must remember that we are dealing with a course, not a bearing. The course should be plotted with the meridian nearest halfway between the last known position and the new position.

On the ground, or in large airplanes, this may be done satisfactorily by estimating roughly the course and distance on the chart, selecting the meridian nearest halfway, laying off the course therewith, and paralleling the line so obtained with a line through the last known position.

To illustrate, in figure 97, A marks the last known position of an airplane and the known data are as follows:

Compass heading in flight_____ 055°
Ground speed (approximate) _____ 110 mph
Elapsed time _____ 1:20:00
Drift angle (wind from left)_____ 10°
Compass deviation on compass heading of 055°_____ 3° W.
Magnetic variation, average, from chart _____ 7° E.

The true course is found in accordance with the rules already given, as follows:

055°   Compass heading
—3°   deviation (westerly)
052°   Magnetic heading
+7°   variation (easterly)
059°   True heading
+10°   drift (wind from left)
069°   True course

The approximate distance covered in 1 hr. 20 min. at 110 mph is 147 miles. By inspection it is seen that 147 miles on a true course of 069° crosses approximately 3° of longitude. The course angle of 069° is measured with the meridian nearest halfway, 1°30' east of A, at any convenient
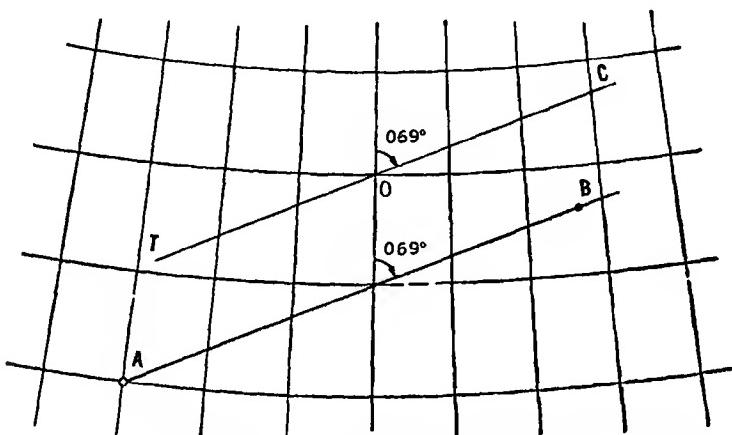
Figure 97.—Plotting on the chart the track, or true course made good.

intersection, O, and the line TC obtained. The line AB, drawn from A parallel to TC, is the dead reckoning track made good; a point, B, on the track line, 147 miles distant from A, marks the position of the airplane by dead reckoning.

In the air, the pilot of a small airplane will have little opportunity for this kind of plotting. Instead, it is assumed that he has plotted his route carefully before taking off, and that he has subdivided it into 10-mile intervals. If his intended true course was determined as 072°, the true course made good (069°) actually lies about 3° to the northward. Estimating the distance of 147 miles along the plotted route (seven-tenths of the distance between the 140-mile and the 150-mile ticks), a point is marked on the chart along an imaginary line at an angle of 3° to the plotted route, and the time noted.

In estimating small angles, it may be of some aid to remember the old formula that an angle of 1° is represented by an offset of 1 in 60. That is, if a line is drawn 60 inches in length, and at one end a perpendicular 1 inch long is erected, a line from the top of the perpendicular to the far end of the 60-inch line will meet it at an angle of 1°. Similarly, 1 centi-

meter in 60, 1 mile in 60, or 10 miles in 600 all represent angles of 1°; 2 miles in 60 represents an angle of 2°, etc.

Applying this principle to the above problem (an angle of 3° at 147 miles), an angle of 1° has an offset of 1 mile in 60, 2 miles in 120, 2½ miles in 150, and 3 miles in 180 miles. An angle of 3° will have an offset 3 times as great, or 7½ miles in 150. A point about 7½ miles north of the plotted route line, at 147 miles from the starting point, represents the dead reckoning position required.

In practice, it must be realized that there are a number of sources of possible error in a position so determined. For example, due to irregularities in handling an airplane, pilots are seldom able to fly a given heading closer than 1°; usually the determination of drift can only be considered as within a degree or two, at best, due to variable winds and difficulties of observation; and even the ground speed can only be considered approximate at times.

In many cases, these various errors tend to cancel out; in others, they may become additive. Pilots should learn to estimate the total error possible in any given case. The dead reckoning position, plotted as described above, should then be considered, not as an actual position, but as the center of an "error circle," at any point within which the true position might lie.

To illustrate, after an hour of flight at an estimated ground speed of 120 mph, it is believed that the total course error may reach as much as 3°. An error of 1° is represented by 1 mile in 60, 2 miles in 120. An error of 3°, then, amounts to 6 miles in 120, and a circle with radius of 6 miles is drawn around the dead reckoning position. If landmarks seen at the end of the hour are not in agreement with those near the plotted position on the chart, they may probably be found somewhere within the circle of error. The pilot is often able to identify his position more quickly by placing this limit on the chart area within which to look for the landmarks seen beneath him.

SUMMARY

The following comparison may serve to fix in mind the procedure in the two general cases of dead reckoning:

Case I: Chart to compass heading:

1. Measure the true course.
2. ADD WIND RIGHT, i. e., add the correction for wind from right.
3. ADD WESTERLY VARIATION.
4. ADD WESTERLY DEVIATION.

Case II: Compass heading to chart:

1. SUBTRACT WESTERLY DEVIATION.
2. SUBTRACT WESTERLY VARIATION.
3. SUBTRACT WIND RIGHT, i. e., for wind from the right.
4. Plot true course on chart.

EXAMPLES

Example 1.—Starting at 10 a. m., a flight is to be made from Scott Field, near Wheeling, West Virginia, to Mayes Airport, Huntington,

West Virginia (Huntington sectional chart). Weather is reported as satisfactory for contact flight. Cruising speed of airplane, 90 mph: wind 15 mph from 045°.

Required.—The distance, compass heading, and time of arrival.

A straight line is drawn on the chart between the two airports, and is found to be a practical route, with two intermediate airports and an abundance of landmarks for checking the route of the airplane in flight.

By means of the border scale of miles the distance is found to be 151 miles.

When the route crosses not more than 3° or 4° of longitude, the course may be measured for the route as a whole, but must be measured with the meridian nearest halfway between the two points, as illustrated in figure 35. By inspection it is seen that the meridian of 81° 30′ is nearest halfway, and the true course, measured with the meridian of 81° 30′, is 219°. The wind, from 045°, is almost directly behind the airplane, and no allowance to compensate for drift is necessary; the true course in this case is therefore the true heading also.

219° true heading
+3° magnetic variation, westerly (from chart)
222° magnetic heading
+2° deviation, westerly, on this heading (from deviation card)
224° compass heading

With a tail wind of 15 mph, the ground speed becomes 105 mph. The total distance of 151 miles will be covered in $\frac{151}{105} \times 60$ minutes, or a little more than 1 hour 26 minutes, making the time of arrival 1126 (11:26 a. m.).

This is checked in flight by noting that the town of Woodsfield, 34 miles southwest of Scott Field, is passed in about 19.5 minutes of flying. By simple arithmetic or by means of a computer (see Chapter VIII) it is easily determined that this corresponds almost exactly to the predicted ground speed of 105 mph. In the same way, the time when the plane should pass Marietta, Parkersburg, Gallipolis, the bends of the Ohio River, or other characteristic landmarks may be determined and noted on the chart. The section below Marietta, where the route follows the general trend of the Ohio River, affords a splendid opportunity for checking the compass heading in flight.

Attention should be given to the number of landmarks along this route. Starting from Scott Field, in about 9 minutes the airplane should pass the town of Jacobsburg, which is located at a road junction and at the end of an abandoned railroad. Note also the race tracks at Marietta, Parkersburg, and Gallipolis, and the dams and locks along the Ohio River.

Note that the portion of the flight between Wheeling and Parkersburg lies within the easterly limits of a "Caution Area." From the note within the area it appears that a flight under contact rules is permissible,

but this should be checked with the air traffic control center, through the nearest airway communication station.

Example 2.—A flight is to be made from Pittsburgh-Allegheny County Airport to Purdue University Airport, at La Fayette, Indiana.

For this flight either the Cleveland and Chicago sectional charts or regional chart 9M may be used. In this case the airplane is fairly fast, dead reckoning (rather than pilotage) will be employed, and the landmarks furnished by the drainage pattern, railroads, and larger cities will furnish sufficient check of position; therefore chart 9M is chosen. The flight will be made only when the weather permits contact flying. ·Cruising speed of airplane 165 mph; wind 22 mph, from 045°.

Required.—The distance, compass headings, and the total flying time.

A straight line between the two airports is drawn on the chart and, by means of the border scale of miles, the distance is found to be 369 miles.

Any long route should be divided into sections crossing not more than 3° or 4° of longitude each, and the true course for each section should be measured with the middle meridian of that section.

After a careful study the route is divided into two sections:

(1) Pittsburgh—longitude 83°

(2) Longitude 83°—Purdue Airport.

Just beyond the 83rd meridian, two rivers and two railroads run north-and-south between Columbus and Marion, Ohio. The heading should be changed in flight as these features are identified. The data for each section are as follows.

Leg No	Ck point No	From	To	TC	WC	TH	Var	MH	Dev	CH	Local distance	Total distance
		Pittsburgh-Allegheny	Purdue-La Fayette								0	369 mi.
1		Pittsburgh	Long 83°	272°	+6°	278°	3° W	281°	1° E	280	162	162 / 207
2		Long. 83°	La Fayette	270°	+6°	276°	0°	276°	0°	276	207	369

PURDUE FLIGHT

The wind correction angle may be determined by means of a computer, or by means of the wind triangle of figure 98, which shows the data for the first section of the flight. Since the ground speed is 179 mph, the first section of the route should be completed in 54 or 55 minutes. If the compass heading and ground speed check out on the first leg, it may be assumed that the wind direction and velocity have remained unchanged, and the same wind corrections can be continued for the second leg; otherwise, revised wind data must be determined and applied. In the foregoing tabulation it is assumed that the wind remains constant. The wind is from the right, and the wind correction angle of 6° is therefore to be

added. It is also assumed that figure 54 represents the deviation card of
the compass to be used on the flight.

Example 3.—A flight is proposed from Pittsburgh-Allegheny County
Airport to Bird Airport, North Platte, Nebraska.

Required.—The distance and compass headings.

The cruising speed of the airplane in this case is relatively low, and
the flight will be chiefly for pleasure. Navigation will consist in large
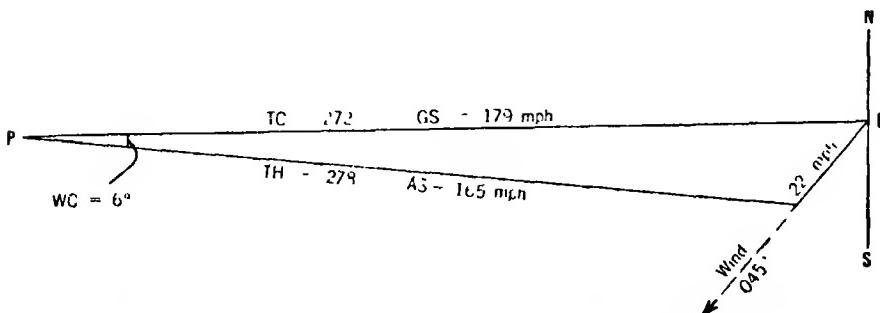
Figure 98.—Graphic determination of wind correction angle and ground speed.

measure of pilotage (contact flying), and the sectional charts will there-
fore be used.

In view of the distance, and the number of sectional charts required
(Cleveland, Chicago, Des Moines, and Lincoln), this route should first be
plotted on the planning chart, then transferred to the large scale charts.

It is found that the straight-line route on the planning chart passes
very close to the airports at Fort Wayne, Moline, and Omaha, and that
these three places are fairly evenly spaced between the two terminals, at
distances of about 275 miles, which is just under the normal cruising
radius of the airplane. The three places mentioned are therefore chosen
as stops.

The first section is now drawn on the planning chart, from Pitts-
burgh-Allegheny County Airport to Fort Wayne Airport. This section
of the route crosses the 84th meridian (the west boundary of the Cleve-
land chart) at latitude 40°58′. On the Cleveland chart, then, a line is
drawn from the airport at Pittsburgh to latitude 40°58′ on the 84th
meridian. This represents the first portion of the route on the Cleveland
chart; by means of the border scale of miles it is found that the total dis-
tance on this chart is 218 miles.

The route from Pittsburgh to Fort Wayne crosses about 5° of
longitude. This section is therefore broken down into two sections, cross-
ing about 2½° of longitude each. The course should be changed at about
longitude 82°30′, which in this case is marked for the pilot by the city
of Mansfield. The true course for the first section is found as 282°; for
the second section, 280°.

In the same way, the other sections of the route to North Platte
are plotted on the remaining charts, and the distances from the various
charts are totaled to obtain the distance for the entire route.

Example 4.—In Notices to Airmen there is reported the erection of a high radio tower which is considered an obstruction to air navigation. The position of the tower is given as latitude 47°04.'5, longitude 120°38'.

Required: To plot the position of the tower on the Seattle sectional chart (pl. IV).

By means of the graduated meridians showing minutes of latitude, on the adjacent meridians (120°30' and 121°) lay off northward from latitude 47° a distance equal to 4.5 minutes of latitude and draw a straight line through the points so obtained. This line represents the latitude of the radio station.

Lay off along the graduated parallels of latitude (46°30' and 47°30') a distance of 8 minutes, westward from longitude 120°30', and draw a straight line between the points so obtained. This line represents the longitude of the radio station (120°30' + 8' = 120°38') and its intersection with the line representing the latitude is the position of the tower.

Example 5.—After an extended period of flying above fog, it is desired to check the position of an airplane by celestial observations, and the latitude and longitude of the dead reckoning position are required.

On the regional charts (pl. III) the meridians and parallels corresponding to whole degrees are subdivided into minutes of latitude and longitude. It is therefore necessary only to draw a north-and-south line through the dead reckoning position to the nearest subdivided parallel and read the longitude, while a straight line east and west permits reading the latitude from the nearest subdivided meridian. The slight curvature of the parallel within the limits of 1° is entirely negligible for all practical purposes.

As already stated, if a scale of nautical miles should be desired, the scale of minutes of latitude—that is, the subdivisions along the meridians—will serve.

QUESTIONS

1. Define pilotage.
2. Define dead reckoning.
3. What are the advantages of dead reckoning over pilotage?
4. What instruments might be used to advantage in pilotage?
5. Is pilotage ever needed in more advanced methods of navigation?
6. What are the two basic problems of dead reckoning?
7. Is "Case II" of dead reckoning ever needed simultaneously with "Case I"?
8. Name the five steps incidental to dead reckoning (Case I).
9. Name the five steps of Case II.
10. What is meant by magnetic variation? compass deviation?
11. Define the following terms and distinguish between them: true course; true heading; track; drift angle; wind correction angle; air speed; ground speed; magnetic heading; compass heading.
12. State the rules for applying magnetic variation, compass deviation, and the allowance for wind.

13. What are the advantages of plotting a route on a planning chart?

14. Describe the method of measuring the true course.

15. In general, what should be the greatest length of route to be flown as one course?

16. Can the true course, true heading, or track ever be the same?

17. What is meant by a "wind triangle"?

18. Describe the standard system for lettering a wind triangle. Under this system what do the following sides always represent: *EW; EP; WP?*

19. When flying true north, a wind correction angle of 10° was applied for an easterly wind—that is, the true heading was 010°. If the pilot reversed his course and flew south, under the same conditions, what should his true heading be?

20. A magnetic course is sometimes printed on a chart; why is a compass course never given?

21. If a true course of 245° were being flown should the correction be added or subtracted (*a*) for wind from 090°? (*b*) for wind from 270°? (*c*) from 180°?

22. With westerly variation, is the magnetic heading greater or less than the true heading?

23. Does deviation of the same compass ever change?

24. Explain the difference between plotting a course and plotting a bearing.

25. What is the approximate rule for estimating an angle of 1°? How could this be adapted to plotting an angle of 3°?

26. Solve the following wind triangles for the missing data; some are under Case I, others under Case II:

	1	2	3	4	5	6	7	8
True course	123	237		030				350
Air speed	120	160	135	170	110	105	140	165
Wind direction	010	010	210	240	270	270	90	210
Wind velocity	20	25	18	30	15	15	27	22
True heading			270		035	192	355	
Ground speed								

27. Determine the compass heading in each case from the following data; the letter *L* or *R* after a wind correction angle indicates that the wind is from the left, or right, respectively:

	1	2	3	4	5	6	7	8
True course	070	330	165	240	040	180	180	355
Wind correction angle	8° R	8° R	5° L	9° R	15° L	8° L	8° R	6° R
Variation	7° W	17° E	4° E	6° W	12° E	3° W	3° W	3° E
Deviation	3° E	3° E	5° W	10° E	2° E	3° W	3° E	4° W
Compass heading								

28. Determine the track, or true course to be plotted on the chart, in each case, from the following data; the letter *L*, or *R* after a drift angle indicates that the airplane is being drifted toward the left, or right, respectively:

	1	2	3	4	5	6	7	8
Compass heading	140	240	035	330	090	270	355	210
Deviation	10° E	3° W	2° W	5° E	1° W	1° W	10° E	0°
Variation	10° E	13° E	9° W	0°	6° E	6° E	6° W	12° E
Drift angle	10° R	8° L	12° L	15° R	20° L	9° L	5° R	6° W
Track (TC)								

Chapter VII.—SPECIAL PROBLEMS OF DEAD RECKONING

THERE *ARE* SPECIAL PROBLEMS

The discussion of dead reckoning might have been concluded with the preceding chapter, which supplies the basic principles for the solution of any problem which might arise in this field. In practice, the relation of some of these problems to the basic principles is not immediately obvious. The conditions met in flight are not always the ideal conditions too often assumed in the textbook. In short, there *are* special problems in dead reckoning.

The preceding chapter has been limited to general principles, in order that they might be thoroughly understood, as a basis for solving the more practical problems presented in this chapter. The present chapter is concerned with the solution of the special problems met in the practice of dead reckoning.

CLIMB AND DESCENT

It has already been pointed out that the forward speed over the ground is materially reduced when climbing and when the motor is throttled back in descending for a landing. For the practice of accurate dead reckoning this must be taken into account. The problem is roughly illustrated in figure 99, where the time and distance during climb,
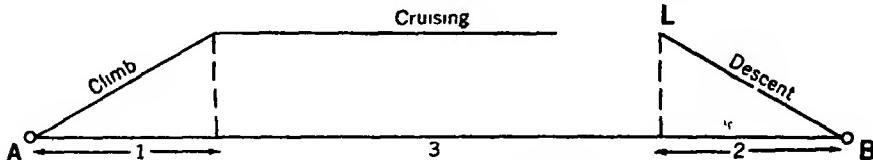
Figure 99 – Climb and descent procedure

descent, and cruising—numbered 1, 2, and 3, respectively—must be combined in order to obtain the correct time and ground speed between *A* and *B*. The point *L* is known as the "Point of Letdown."

The rate of climb and rate of descent depend upon the performance characteristics of the particular airplane. For example, for a given airplane the rate of climb is 500 ft./min. (feet per minute) at an indicated air speed of 120 mph, and the rate of descent is 400 ft./min. at 130 mph.

It has also been pointed out that the indicated air speed is too low by approximately 2% for each 1,000 feet of altitude; that is, at 5,000 feet the indicated air speed must be increased by approximately 10% $(5 \times 2\%)$.

In practice, the correction to the indicated air speed during climb and descent is found very simply by adding the cruising altitude and the elevation of the point of take-off, both in thousands of feet. Thus, if the cruising altitude is 6,000 feet, and the point of take-off is 1,500 feet above sea level, the correction is $6 + 1.5 = 7.5\%$ of the indicated air speed. The explanation is as follows:

Since a constant rate of climb is maintained, the average air speed will suffice. This may be obtained by adding to the indicated air speed 2% of the altitude at take-off and 2% of the altitude at cruising altitude, then dividing by two. It may be obtained more easily by adding only 1% in each case and *not* dividing by two.

This is made clearer in figure 100, from which it is seen that $(2\% \times 1.5 + 2\% \times 6) \div 2$ is equal to 7.5%; or $2\% \times 3.750$ (the average altitude during climb, in thousands of feet) is also equal to 7.5%.
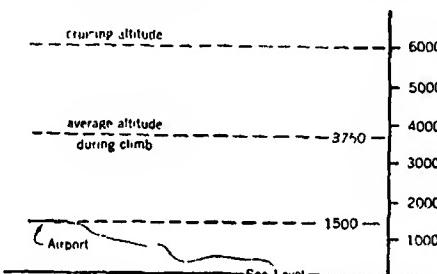
Figure 100.—Correction to indicated air speed when climbing or descending

The same result is obtained more easily by adding 1% for each 1,000 feet of take-off altitude (1.5) and 1% for each 1,000 feet of cruising altitude (6.0). The following example illustrates all phases of this problem.

The data for the particular airplane and flight are as follows:

R/C = 500 ft./min. at 110 mph
R/D = 400 ft./min. at 105 mph
AS = 135 mph, at cruising
TC = 060°
Distance = 380 miles
Variation on climb = 5° E
      on descent = 2° W
      on cruise = 2° E
Deviation (as in figure 54)   = 1° W
Cruising altitude   = 7,000 ft.
Elev. of airport at take-off   = 1,000 ft.
Elev. of airport at destination = 650 ft.
Ceiling at destination   = 800 ft.
Average wind on climb   = 010°, 25 mph }
Average wind on descent = 280°, 32 mph } from "winds aloft chart"
Wind on cruise   = 300°, 38 mph }

Separate wind triangles must be solved for the three portions of the flight: climb, descent, and cruise. The results are as follows:

1. Climb: 1,000 ft. = airport elev.
             7,000 ft. = cr. altitude
             $\overline{8\%}$ = correction to AS on climb
             110 mph + 8% = 119 mph, true AS;
             6,000 ft. of climb at 500 ft./min. = 12 min. on climb;
             from wind triangle:
                 TH and GS = 050°, 101 mph;
                 101 mph for 12 min. = 20 mi. on climb;
                 CH = 050° — 5° E. Var. + 1° W. dev. — 046°.

2. Descent: 650 ft. = airport elev.
             800 ft. = ceiling
             $\overline{1,450}$ ft. = elev. of ceiling, for "break through";
             7,000 ft. = cr. altitude;
             $\overline{8.45\%}$ = correction to AS on descent;
             105 mph + 8 45% = 114 mph, true AS;
             5,550 ft. of descent at 400 ft./min. = 13.9 min. on descent;
             from wind triangle:
                 TH and GS = 049°, 135 mph;
                 135 mph for 13.9 min. = 31 3 mi. on descent;
                 CH = 049° + 2° W. Var. + 1° W. dev. = 052°.

3. Cruise: 20   mi. on climb   380   mi. total
             +31.3 mi. on descent   —51 3 on climb and descent
             51.3 mi. $\overline{328.7}$ mi. on cruise
             from wind triangle:
                 TH and GS = 045°, 150 mph;
                 328.7 mi. at 150 mph = 2.11:28 on cruise;
                 CH = 045° — 2° E. Var. + 1° W. dev. = 044°.
                 2:11:28 on cruise   328.7 mi.
                 +0:12:00 on climb   20.0
                 $\overline{2:23.28}$ and $\overline{348.7}$ mi. to "point of let-down"
                 +0:13:54 on descent 31.3
                 2:37:22   and $\overline{380.0}$ mi. to "break through" over
                                               destination.

A standard printed form will greatly expedite performance of these operations, but from the foregoing it may be seen that each individual step is simple and is easily accomplished.

If the above procedure is ignored and the whole distance is flown on the basis of the cruising altitude wind triangle, the total time is obtained as 2:32:00, nearly 5½ minutes less than the more exact figure. Under contact flight this difference would be of little importance, but at 150 mph 13.5 miles would be made good in that time—and under instrument flight conditions this difference might be serious.

The difference in this problem is rather less than usual, and a general rule used by pilots on instrument flights when there is no opportunity for more exact methods, is to add to the time obtained for the total distance at the one cruising speed, 1 minute for each thousand feet of cruising altitude.

In many cases the average temperature for the climb and descent is not available, and the 2 percent rule must be relied upon, as in the example. When cruising altitude is reached, however, the actual tem-

perature at that level can be observed, and the true air speed can be obtained more exactly with a computer, as explained in the next chapter.

OFF-COURSE CORRECTIONS

Intentional departures from the plotted route are sometimes made in order to avoid unfavorable weather conditions, or for other reasons; often, however, the departure is unintentional and is not realized until position is determined in flight, by reference to known landmarks. Ordinarily, when a departure from the intended track is noted, a new compass heading to the destination is determined by applying variation, deviation, and a revised allowance for wind. Under other conditions it may be desired to return to the intended track and complete the flight as originally planned.

To return the plane to the intended track many approximate methods are practiced. Some of these are unsound in principle since they do not take into account the reasons causing the departure. For example, in figure 101, a pilot is flying from E to D, 100 miles due east, at 100 mph. After
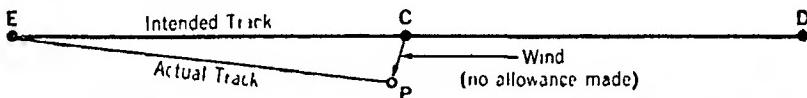
Figure 101.—Departure from intended track due to failure to apply correction for wind.

30 minutes of flight when he should be at C, he finds himself directly over a town at P. Since he was making no correction or allowance for wind, the line CP represents the direction and velocity of the wind; EP is the track, and the angle CEP is the drift angle.

In figure 102, on another occasion a pilot is flying between the same two points, making allowance for a northwest wind of 30 mph. After
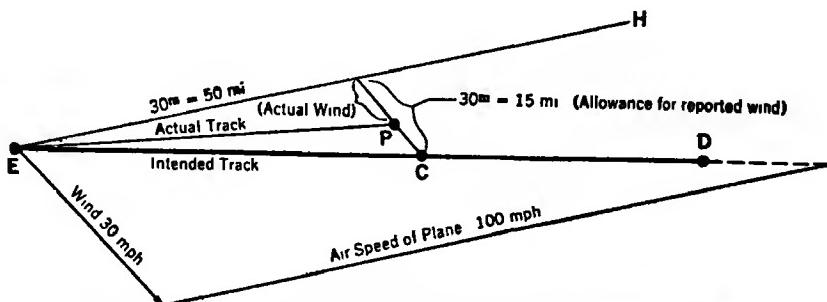
Figure 102.—Departure from intended track due to over-correction for wind.

proceeding on the proper heading EH for 30 minutes he should be at C, but finds himself over a town at P, due to the fact that the wind was only 20 mph, instead of 30 mph as reported. It should be evident that to return to the intended track under these conditions will require a procedure different from that required in the preceding figure.

A good general rule to follow is to head the airplane toward the intended track at an angle of about 45° thereto. Allowance for wind

can be made, taking into account the wind data just learned from the determination of position, and the time of arrival over the plotted route can be found with a fair degree of accuracy.

The simplest method (if the wind is at such an angle to the plotted route that it is practical) is to line the airplane up with the wind, approaching the intended track directly into the wind (fig. 101), or with the wind (fig. 102). In either case the ground speed may be known from the air speed of the airplane and the wind velocity, and the time of arrival over the intended track is most easily determined.

In figure 103, the true course from A to B is 270°, with true air speed 135 mph; wind 045°, 20 mph; total distance 328 miles. Through
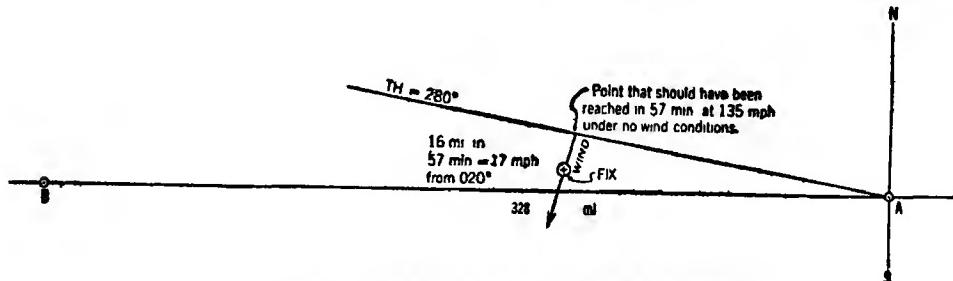
Figure 103.—Completing a flight after departure from the intended track.

a combination of pilot errors, a true heading of 280° was held for 0:57:00 (0 hr. 57 min. 00 sec.), when a fix was obtained over a point 132 miles from A and 8 miles to the right of the plotted route. Find,

1. Wind direction and velocity;

2. Course and distance from fix to B; and

3. Data for returning to the charted route and continuing the flight to B along it.

The true heading is laid off, and the point along the heading which the airplane would have reached in 57 minutes at its true air speed of 135 mph. The fix is next plotted, and a line joining the two represents the action of the wind during the flight. From this it is seen that the wind is from 020° at 17 mph.

The true course from the fix to B is 267°. By constructing another wind triangle, the true heading is determined as 274°, ground speed 141 mph.

If it is preferred to return to the charted route, the heading of 200° is adopted (020° + 180°), and the airplane flies with the wind at a ground speed of 152 mph. At this rate it will take only a little more than 3 minutes to cover the 8 miles or so to the charted route, at which time a true heading of 277° should be flown in order to make good the intended true course of 270° under the revised wind data. The revised ground speed is determined as 140 mph.

In flight, of course, it is impractical to construct wind triangles in most cases. The true heading and air speed might be plotted on the chart itself, and a line on the chart from that point to the fix would represent the wind direction and velocity. With these data, revised estimates of

heading and ground speed can be made or, better, can be determined
with a computer, as explained in a later chapter.

DOUBLE DRIFT

It is essential to obtain the latest available wind and weather in-
formation before undertaking any flight, in order to plan intelligently.
It is not always possible to obtain the desired information, however;
even when it is, it should never be relied upon without making every
effort to verify it in flight. It was probably failure to do this that forced
Captain Rickenbacker's crew down in the Pacific.

The most satisfactory method of determining wind data in flight
is known as the "double drift method." Using this method, two headings
are flown approximately at right angles to each other, and the drift
angle on each heading is observed. When these are plotted as shown in
figure 105, the wind direction and velocity are obtained. When the
variation and deviation are not large, the compass headings may be
plotted without converting to true headings, since the wind cannot be
considered constant nor its determination accurate to within several
degrees, at best. When either variation or deviation is appreciable, it
is better to convert the compass headings to true headings for the plot—
a matter of only a few moments for the practiced navigator.
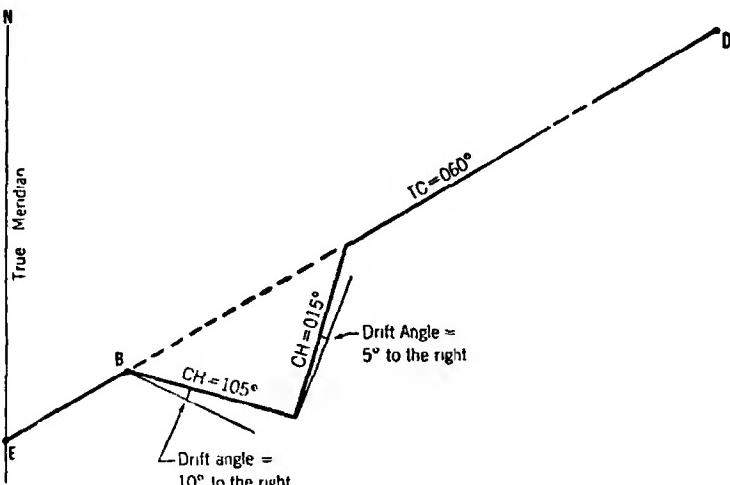
Figure 104.- Measuring the two drift angles

In practice, a pilot desiring to determine the wind usually heads
45° to one side of his route and measures the drift angle, then turns
through approximately 90° and flies a heading 45° to the other side of
the route and again measures the drift angle. Under average conditions,
the airplane should be approximately over the original track when the
second drift angle is obtained, and the original heading is resumed while
the wind data are determined. This procedure is illustrated in figure
104, where the original true course was 060°.

The method of plotting the two drift angles is illustrated in figure 105. In the figure it is assumed that a pilot was flying a true heading of 355° at a true air speed of 110 mph, in order to make good an intended track of 360°, when it was decided to check wind by double drift.
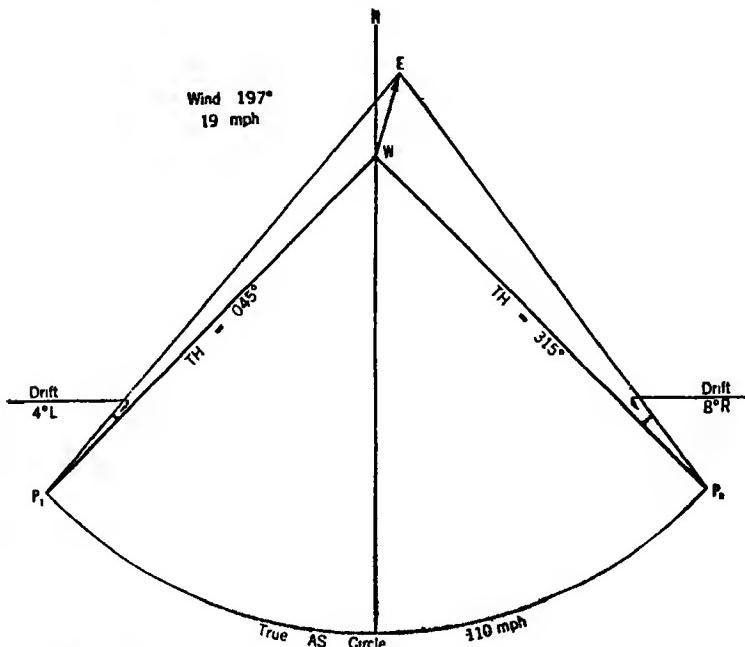
Figure 105.—Graphic plot for determining of wind by double drift method.

On a compass heading of 045° the observed drift angle was 4° left; on a heading of 315° the drift angle was 8° right.

As in many of the problems of dead reckoning, it is convenient to make use of an "air speed circle"; by drawing one such arc (or circle) all measurements of air speed are accomplished at once. In this case, the two headings (045° and 315°) are plotted from points on the air speed circle (P_1 and P_2) TOWARD the center W. The observed drift angles are laid off directly, to the left or right of the plotted headings. The line from the center W to the intersection E of the two drift lines, represents the wind direction and velocity, measured as 197° at 19 mph. It is the third side of both wind triangles, the other two sides in each triangle representing the heading and air speed, and the track and ground speed.

The plotting just described is the most natural, and the easiest to visualize: left drift is laid off to the left, right drift to the right. It is the method that must be used with some of the more popular air navigation computers (see fig. 136). Its one disadvantage is that it does not strictly conform to the standard system of lettering, and the wind vector is labeled as WE, not EW. To avoid this, many prefer the method shown for the same problem in figure 106.

In this case, the two headings (045° and 315°) are plotted FROM the center W to meet the air speed circle at the points P_1 and P_2, and

the drift angles observed are plotted from those points. Conveniently enough, if 4° left drift is observed on the heading of 045°, one may think of himself as standing at P_1, looking back toward the center of the circle, and lay off the *4° to his left* (to the left of P_1W), to obtain the desired track line. That the track so obtained does represent the observed drift angle may be seen by thinking of the flight as having started from W in
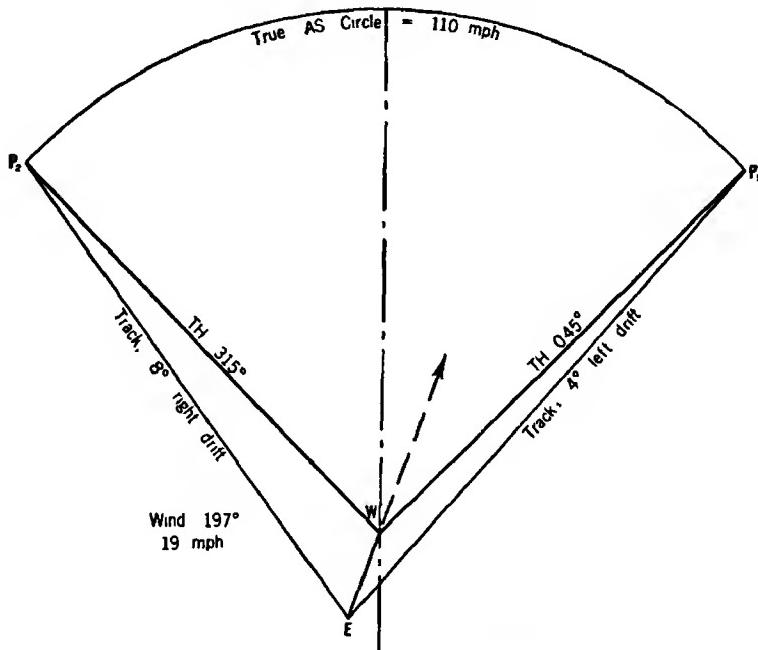
Figure 106.- Graphic plot for determination of wind by double drift (alternate method).

the direction of WP_1, and drifting parallel to the track line EP_1. From this view it is apparent that the aircraft has drifted toward the left, and that the angle between its heading and its track (the drift angle; see p. 108) is 4° The triangle EWP_1 is, in fact, comparable to the triangle EWP in figure 84.

In the same way, the 8° right drift observed on the heading of 315° may be laid off from P_2, to the right of P_2W. The intersection of the two tracks, or drift angles, is designated as E, and EW represents the wind direction and velocity. This method has the advantage of following the conventional lettering.

By rechecking, it is found that with this wind the true heading should be 357° in order to make good the desired true course of 360°.

Figure 107 is a graph for obtaining from the two drift angles the proper allowance for wind and the ground speed that will be made good, without the need for plotting. The ground speed, unfortunately, can be obtained by this method only in terms of percent of the true air speed. The following example illustrates the use of the graph.
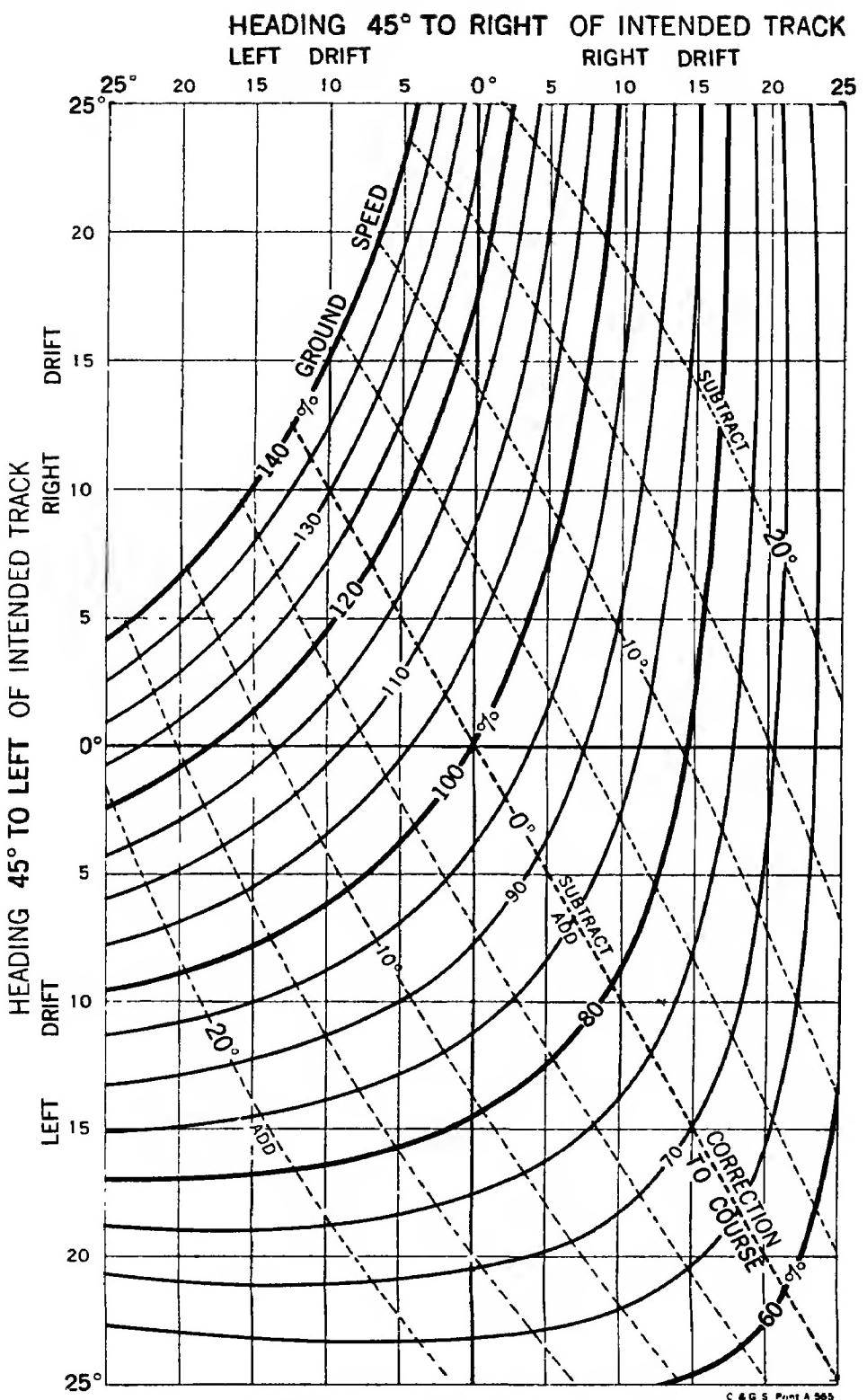
FIGURE 107 · Graph for finding the wind correction angle and ground
speed by the double drift method
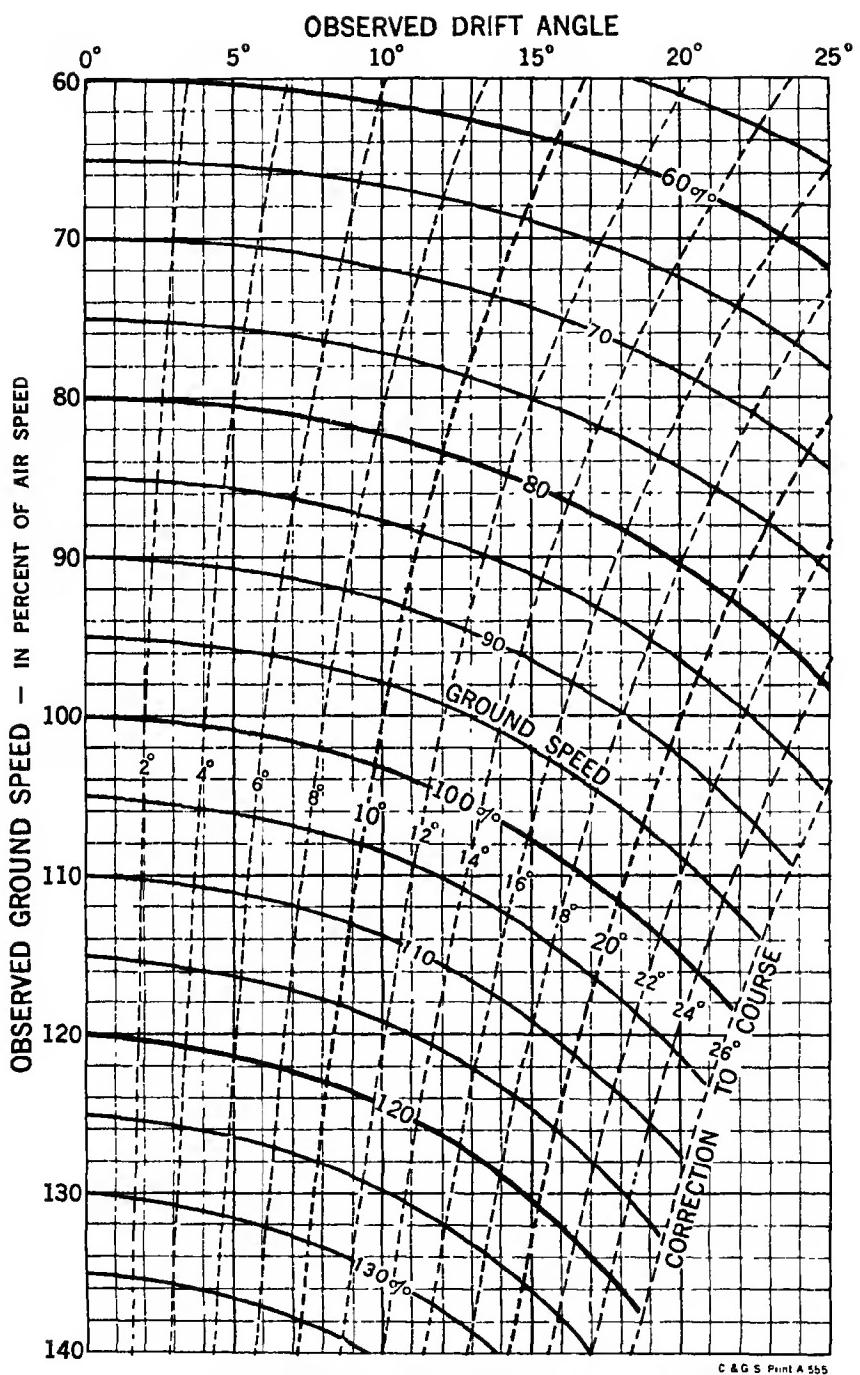
FIGURE 108 - Graph for finding the wind correction angle and ground
speed from one observation with a drift indicator

A pilot desiring to make good a compass course of 078° flies first on a compass heading of 125° (about 45° to the right), then on a heading of 35° (about 45° to the left), observing the drift angle on each heading. On the first heading a drift angle of 15° to the right was obtained; on the second, a drift angle of 5° to the left. Find the correction to the course for wind, and the ground speed that will be made good.

At the top of the graph are shown the drift angles for the heading 45° to the right of the intended track; follow the vertical line corresponding to a drift angle of 15° to the right down to its intersection with the horizontal line for a drift of 5° to the left, and read 7° correction to be subtracted from the course, and a ground speed of 77 percent. The compass heading to be flown, then, is 78° — 7° = 71°, and the ground speed will be 77 percent of the air speed.

With figure 108 it is possible to obtain the same information, from one observed drift angle, provided the drift sight is also equipped for the determination of ground speed. In this case the procedure is as follows:

1. Turn the airplane along the no-wind compass heading to the destination.

2. Note the drift angle and the ground speed being made good.

3. With these data read directly from the graph the correction for wind, and the ground speed that will be made good, in percent of air speed.

This method is limited only by the accuracy with which the ground speed can be determined. With some drift indicators fairly good determinations of ground speed are possible; at other times this factor can be definitely known by reference to landmarks, radio marker beacons, etc. Whenever the ground speed can be satisfactorily determined, this method is the quickest and most satisfactory, since no departure from the course is necessary in order to make the drift-and-ground speed observations. The use of this graph is illustrated in the following example.

An airplane flying at an air speed of 140 mph is being flown on the no-wind heading when a drift angle of 11° to the right is observed with a drift indicator, and the ground speed is determined as 153 mph. Find the correction for wind and the ground speed that will be made good along the intended track.

The ground speed of 153 mph is 109 percent of the air speed of 140 mph. Follow the vertical line corresponding to an 11° drift angle down to the (interpolated) horizontal line for 109 percent and read, from the nearest red curve, 12°, the correction for wind; the nearest black curve, 105 percent, indicates that a ground speed equal to 105 percent of the air speed will be made good along the intended track; 105 percent of 140 mph = 147 mph. Since the drift is to the right, the wind is from the left, and the 12° must be subtracted from the true course to obtain the true heading.

RADIUS OF ACTION

By radius of action is meant the distance an aircraft may fly, with a given amount of fuel and given wind conditions, and still return to the starting point. The solution of this problem also includes the headings to be flown on the flight out and on the return trip, the ground speed in each direction, and the time to turn back.

This problem is important to the private pilot in determining how far (or how long) he may fly in a particular direction and still return to the starting point before dark; how long he may fly over scenic regions and still be certain that he has enough fuel for the return trip, and so on. It is important to the commercial pilot when the weather at his destination is doubtful and he wishes to know how long he may continue toward his destination and still be able to return to his starting point, if need be.

Favorable winds reduce flying time for a one-way trip, but if the same wind continues for the return flight the round trip always requires more flying time than it would if there were no wind. In other words, for a two-way trip wind is always a hindrance, never a help (unless the wind changes during flight so as to afford a tail wind in both directions).
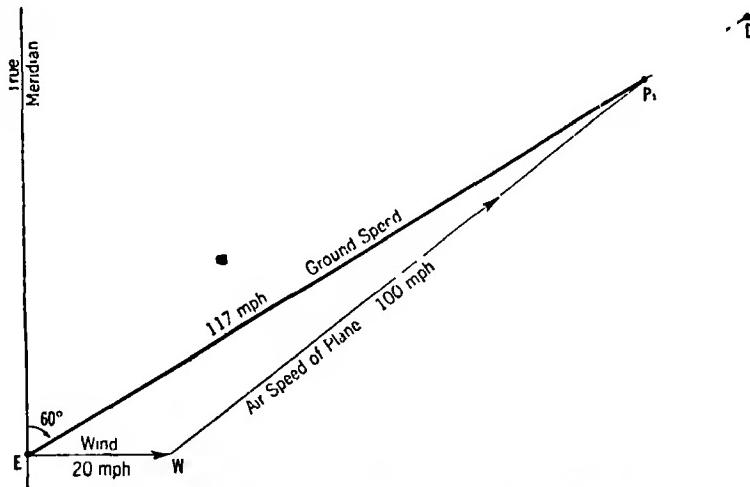
Figure 109.—Radius of action; wind triangle for flight out.

Radius of action problems consist of two parts, each of which may be solved by a wind triangle. To illustrate, let it be required that an airplane fly from E (fig. 109) as far as possible toward a distant point D, and return to E. Cruising speed of airplane 100 mph, wind 20 mph from the west (270°), true course 060° for trip out, 240° for return flight. The total time available is 3 hours. Figure 109 is the wind triangle for the flight out, figure 110 the triangle for the return flight. In each case the correct heading to fly is ascertained, and the ground speed that will be made good along the intended track.

In practice, these two triangles are usually combined into one figure, as shown in figure 111, in order to save time in laying off angles and dis-

tances. They may also be combined as shown at reduced scale at the upper left of figure 111, if preferred.

Having found the ground speed out (GS_o) and the ground speed back (GS_b), the time out (t_o) or the time to turn may be found from the follow-
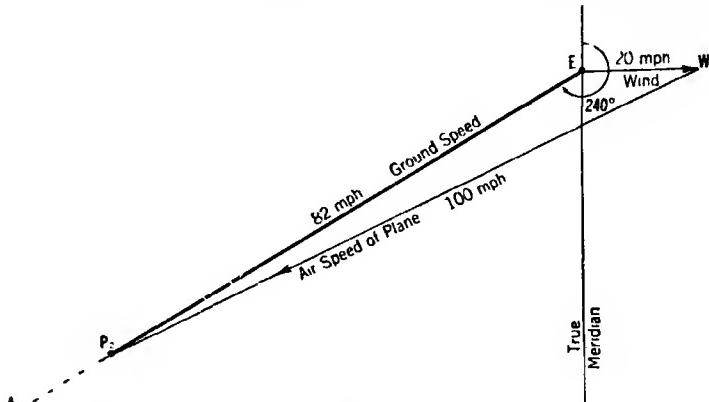
Figure 110.—Radius of action; wind triangle for return flight.

ing formula, in which T is the total time available (in practice, T is often designated as FHA—Fuel Hours Available):

$$t_o = T \times \frac{GS_b}{GS_o + GS_b}$$
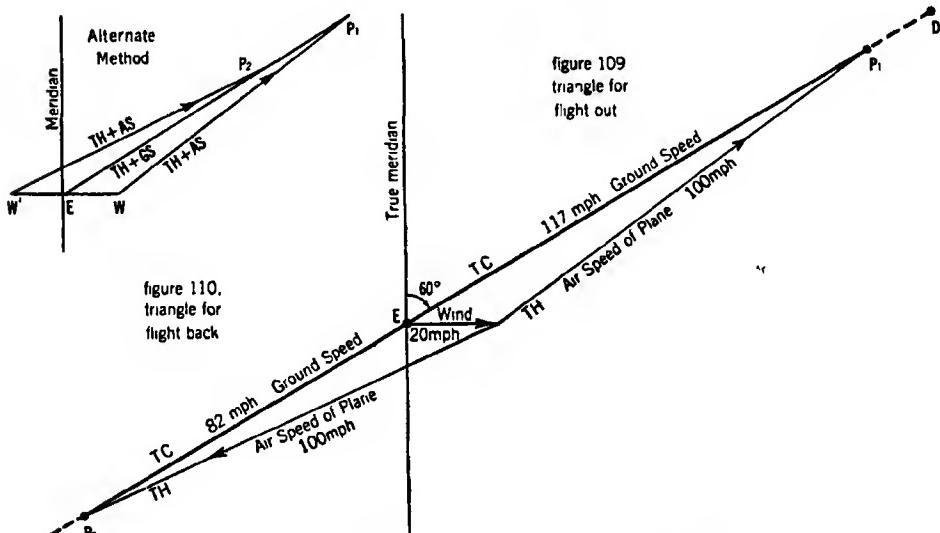
Figure 111.—Radius of action; triangle for flight out combined with triangle for return flight.

In the example just given, then

$$t_o = 3 \text{ (hrs.)} \times \frac{82}{117 + 82} = 1.24 \text{ hrs.} = 1:14:24$$

and the radius of action (R/A) is equal to the time out multiplied by the ground speed out: $R/A = 1.24 \times 117 = 145$ mi.

The combined wind triangles of figure 111 are plotted on a 1-hour basis. The radius of action per hour may be obtained from the formula:

$$R/A/hr. = \frac{GS_o \times GS_b}{GS_o + GS_b}$$

It may also be obtained graphically from figure 111 if desired. The procedure is illustrated in figure 112, which is the same as figure 111, with the
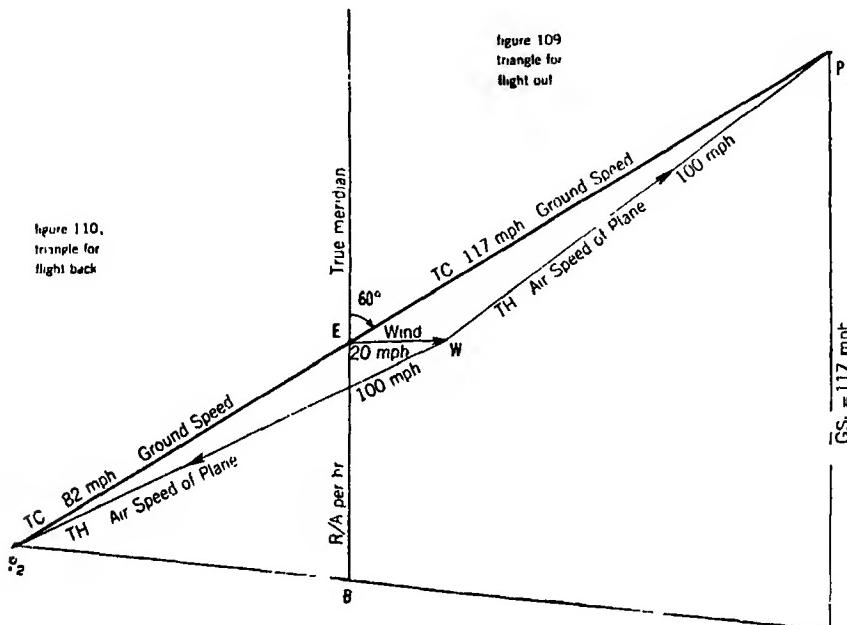
Figure 112 Graphic determination of hourly radius of action

addition of the line P_1A parallel to the true meridian and equal to the GS_o, and the line P_2A, intersecting the true meridian at B.

By simple geometry, in the similar triangles EBP_2 and P_1AP_2,

$$\frac{EB}{EP_2} = \frac{P_1A}{EP_1 + EP_2}, \text{ and } EB = \frac{P_1A \times EP_2}{EP_1 + EP_2}$$

But $P_1A = EP_1 = GS_o$ by construction, and $EP_2 = GS_b$; therefore $EB = \frac{GS_o \times GS_b}{GS_o + GS_b}$, which is the formula for R/A/hr. The line EB therefore represents the radius of action per hour for each hour of flying time available. EB is measured on figure 112 as a little more than 48 mph; this is multiplied by 3 (the total number of hours available) to find the total radius of action: $48 \times 3 = 144$ miles, differing by only 1 mile from the computed radius.

The development of the formulas for radius of action is quite simple, and is given here in order that it may be more thoroughly understood. The following abbreviations are required in addition to those already used:

t_b = time back; d_o = distance out = distance back,

then,

$$t_o = \frac{d_o}{GS_o} \text{ and } t_b = \frac{d_o}{GS_b}$$

$$t_o + t_b = T = \frac{d_o}{GS_o} + \frac{d_o}{GS_b} = \frac{d_o\,(GS_b) + d_o\,(GS_o)}{GS_o \times GS_b},$$

$$= \frac{d_o\,(GS_b + GS_o)}{GS_o \times GS_b}$$

$$d_o = T\,\frac{GS_o \times GS_b}{GS_o + GS_b}$$

$$\text{But, } t_o = \frac{d_o}{GS_o} = T\,\frac{GS_o \times GS_b}{GS_o + GS_b} \times \frac{1}{GS_o} = T\,\frac{GS_b}{GS_o + GS_b}$$

$$\text{and } t_b = \frac{d_o}{GS_b} = T\,\frac{GS_o \times GS_b}{GS_o + GS_b} \times \frac{1}{GS_b} = T\,\frac{GS_o}{GS_o + GS_b}$$

From the formula for the radius of action per hour it should be obvious that the radius of action is the same whether the flight is with the wind or against the wind. If the example illustrated in figure 111 were reversed, figure 110 would represent the flight out, figure 109 the return flight, and the same values would be used to compute the radius of action.

It is also of interest that minimum radius of action exists with wind parallel to the route (head or tail winds); maximum radius occurs with the wind at about right angles to the route.

CRUISE CONTROL

Closely related to radius of action problems are those of flight performance versus *predicted* performance, usually referred to as "cruise control." Both the predicted and the actual performance are plotted in the form of a graph, which has almost universally become known as a "Howgozit" chart; see figure 113.

On the Howgozit chart, the curve *A* represents predicted gasoline consumption, the broken curve *B* actual consumption during the flight. It is apparent from the figure that the actual performance at any given time was better than that anticipated. For example, at 1,000 miles out the predicted fuel consumption was 4,500 lbs., while the actual consumption was only 4,200.

The curve *C* represents the total fuel available for the flight, 7,500 lbs. Curves *D* and *E* are based on the assumption that one of the four engines has failed, and that the flight must be completed, or must return, on 3 engines. It is further assumed that the airplane arrives in either case with empty tanks, and the 3-engine fuel consumption curves are plotted backward, as shown.

At any point during flight, then, the vertical distance between the actual consumption curve *B* and curve *D* represents the fuel reserve in case the airplane must return. The point where curve *D* intersects the actual fuel consumption curve *B* is called the "point of no return," since the curves show that the total fuel available would be used in flying to that point and back; if the flight continued beyond that point there would be insufficient fuel to return.

The vertical distance between curve *B* and curve *E*, for any given number of miles out, represents the fuel reserve at that point.

Strictly speaking, this is not a navigational problem, but rather one of airplane performance. It was introduced here to show the general method of checking performance in flight without loss of time. It shows at once whether more or less fuel than anticipated has been burned, whether enough fuel remains to return or to continue to the destination, and when a decision MUST be made (by reference to the point of no return) as to whether or not an alternate airport should be used.

ALTERNATE AIRPORT PROBLEM

For all flights on instruments an alternate airport must be named— that is, one for which it is certain that ceiling and visibility will not be lower than the specified minimum. The problem is to determine how far (or how long) an airplane may be flown toward its destination before turning to the alternate, if advised that this is necessary.

For example (fig. 114), a pilot leaves an airport at *E*, for a distant point *D*, with just 4 hours' fuel supply, aside from the required reserve. (Regulations require that sufficient fuel be carried for flight to the destination, then to the alternate airport, then for 45 minutes of cruising.) Weather conditions at *D* are uncertain, but conditions at *A* are satisfactory
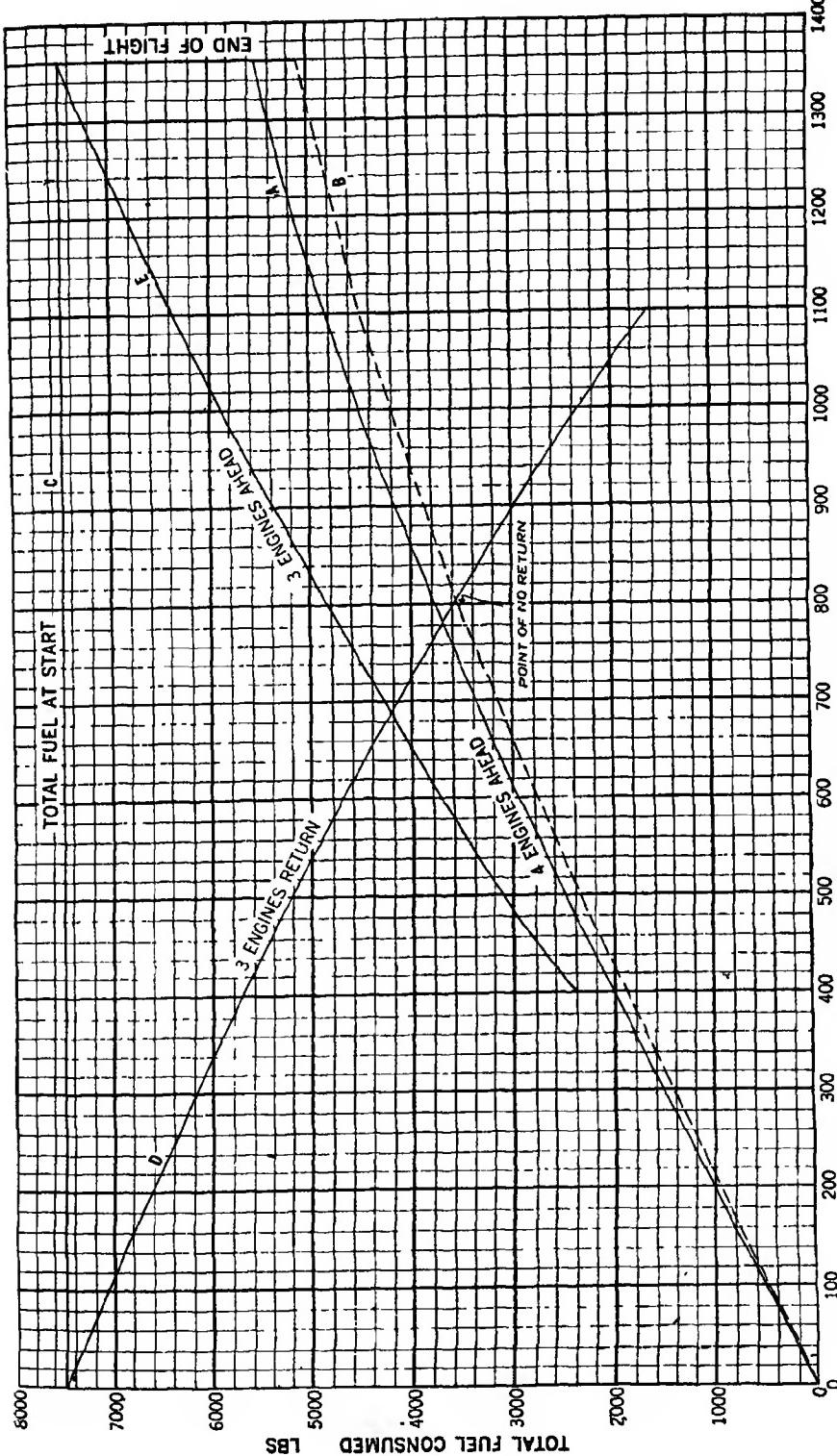
Figure 113.—Cruise control: the "Howgozit" chart.

and are expected to remain so. How far may he proceed toward D and still have fuel enough to reach A if advised by radio that the weather at D has closed in altogether?

The known data are as follows:

$ED = 350$ miles, true course 230°
$DA = 140$ miles due north
Air speed of airplane, 100 mph
Wind, 30 mph from 090°

The first step is to plot the three points, E, D, and A, in their proper relative positions. The line ED, drawn at an angle of 230° to the true meridian, represents the intended track, or the true course it is desired to make good.

Since fuel is available for 4 hours, figure 114 is constructed as a "4-hour wind triangle"—that is 4 times the wind velocity and 4 times the
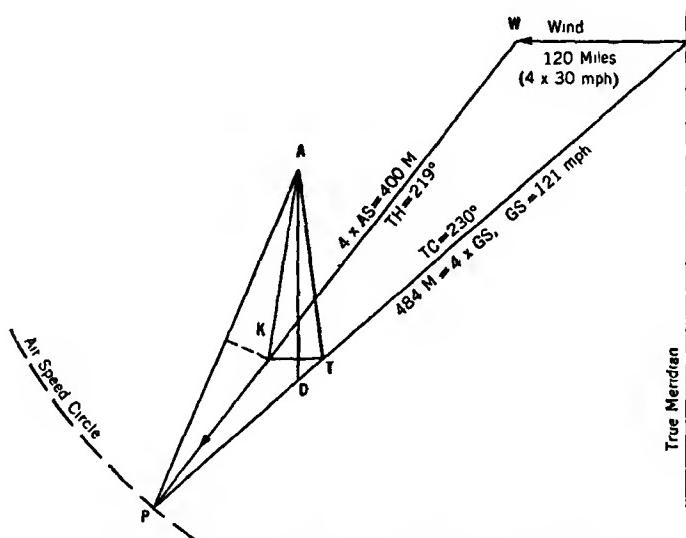
Figure 114. Alternate airport problem (for whole flight).

air speed are plotted, and 4 times the ground speed is obtained. WP is the true heading required, and P is the point on the intended track which the pilot could reach in 4 hours. A perpendicular bisector to the line AP is drawn, making $KA = KP$ by construction. Since the pilot could fly an air distance equal to WP in 4 hours, he could also fly a distance equal to $WK + KA$. The airplane is actually tracking the line EP, and the point of turning T is found by drawing KT parallel to the wind vector; TA is the true course after turning toward A, and KA is the true heading.

In figure 114 it is apparent that the triangles PKA and TKA furnish the key to the solution. In figure 115 these triangles are enlarged by extending the line PA to intersect at P_2 an arc drawn from W with radius $= WP$. Since $WP_2 = WP$ and the angle WPA is identical, triangles PWP_2 and PKA are similar; also triangles TKA and EWP_2. Therefore EP_2

represents the true course after turning toward A, and WP_2 the true heading.

Now let us assume the triangles PWP_2 and EWP_2 have been enlarged until EW represents the wind for 1 hour (instead of 4). Then all parts of these triangles are enlarged proportionately and the whole figure be-
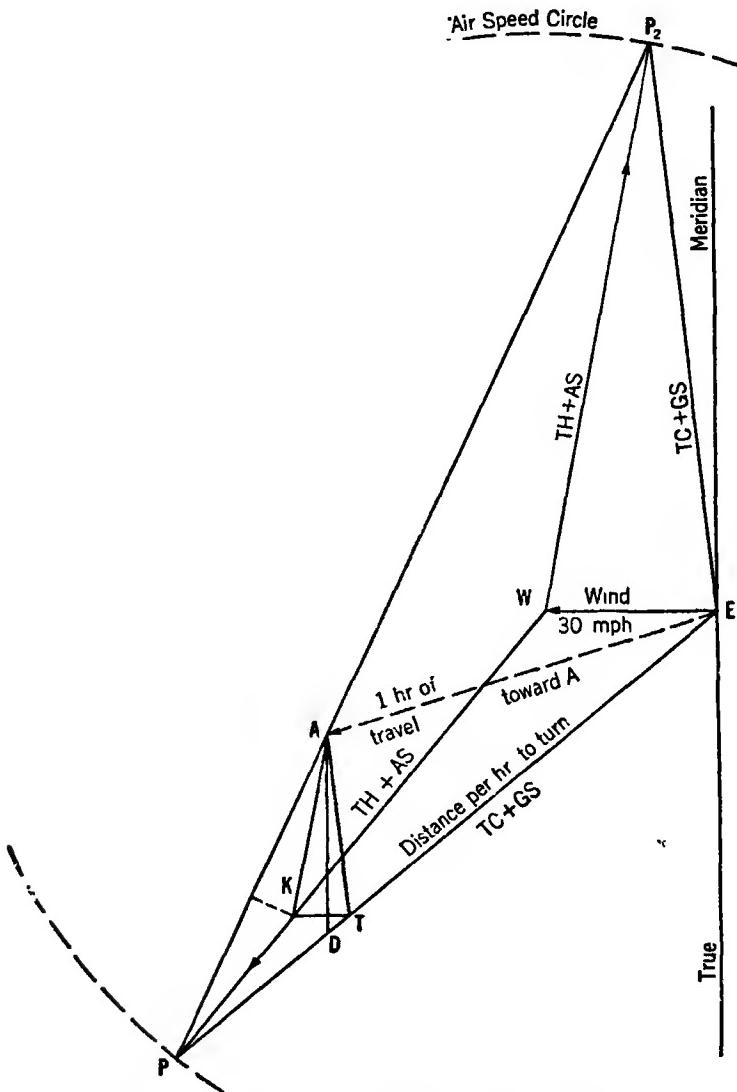
Figure 115.—Alternate airport problem (development of 1-hour plot).

comes a 1-hour plot. EA is merely the direction toward the alternate airport A, and one-fourth the distance; ET is the distance *per hour* to the point of turning, and is scaled as 82 miles. Since 4 hours are available, the distance to the point of turning is $4 \times 82 = 328$ miles; the time to the point of turning is found by dividing this distance by the ground speed

EP, which is measured as 121 mph: 328 ÷ 121 = 2.71 hours, or 2:43:36.[4]

The alternate airport problem is essentially the same as the problem of flight from a moving aircraft carrier. To make the two problems identical it is only necessary to suppose that during the flight the "carrier" has moved from the position of the airport of origin to the position of the alternate airport. In fact, some are able to understand the principles more easily when explained in those terms. For this reason the following additional example is given.

It is required that a pilot fly from *E* (fig. 116) as far as possible toward a distant point *D*, and still be able to return to an alternate air-
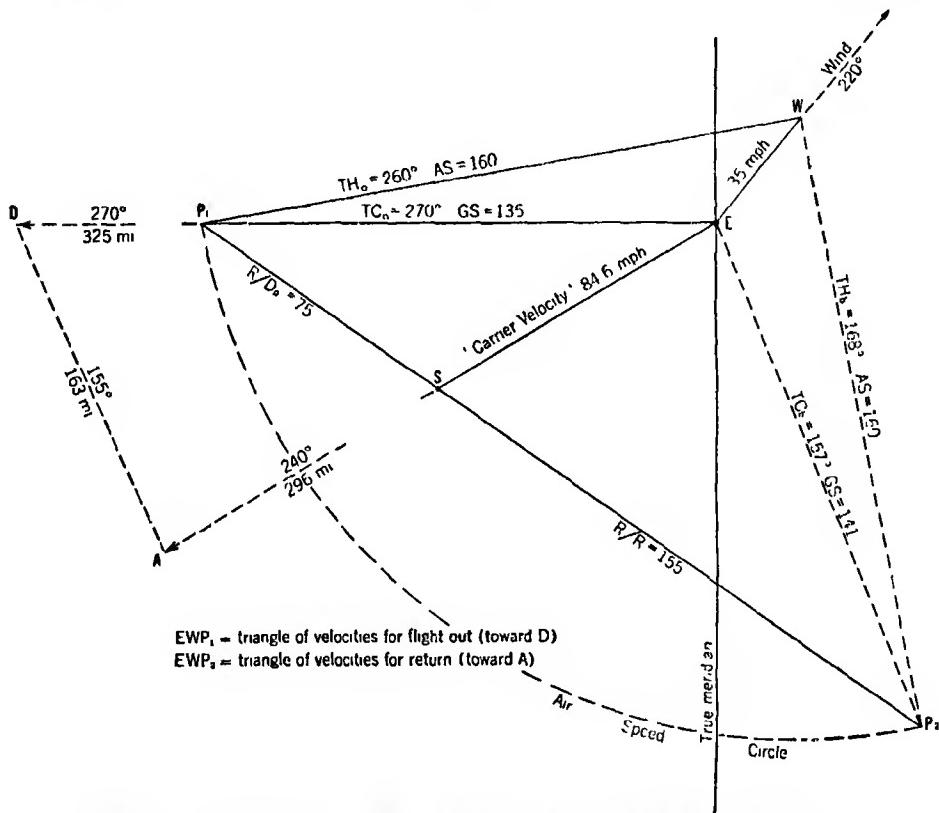
Figure 116.—Radius of action when turning back to an alternate airport (1-hour plot).

port at *A;* he has fuel for 3.5 hours of flight, aside from the required reserve. The other data are as follows:

> *ED* = 325 miles, true course 270°
> *DA* = 163 miles, 155°
> *EA* = 296 miles, 240°
> Air speed of airplane, 160 mph
> Wind, 35 mph, from 220°

---

[4] This method adapted from an explanation suggested by Professor L. W. Whitehead, Pennsylvania State College.

Having drawn the true meridian, construct the wind triangle EWP_1. This is the triangle for the flight toward D, and determines the wind correction angle and ground speed.

Next, it is assumed that the point E is an aircraft carrier, steadily in motion toward A. At the end of the 3.5 hours it must be at A to receive the airplane, and its rate of travel is therefore 296 (mi.) ÷ 3.5 (hrs.) = 84.6 mph. This is indicated in figure 116 as the "carrier velocity."

As explained more fully in the next section ("Interception"), P_1S is the bearing which must be maintained between the aircraft and the "carrier" throughout the flight—whether the aircraft is proceeding along the original course or has turned toward the carrier. The line P_1S is therefore drawn and extended well beyond S, intersecting an arc swung from W with radius equal to the air speed, at P_2. Finally, EP_2 and WP_2 are drawn, representing the true course and the true heading, respectively, from the point of turning to the carrier (or alternate airport).

The triangle EP_1P_2 may now be considered as an ordinary radius of action problem. SP_1 is the distance per hour (the rate of departure, R/D_p) that will separate the aircraft from the carrier as long as it remains on the original course, and therefore represents the "GS_o." SP_2 is the distance per hour (rate of return, R/R) at which the aircraft will return to the carrier after turning, and represents the "GS_b." SP_1 and SP_2 are measured on figure 116 as 75 and 155 mph, respectively. Using the regular radius of action formula, then,

$$t_o = T \frac{GS_b}{GS_o + GS_b} = 3.5 \frac{155}{75 + 155} = 2.36 \text{ hr.} = 2:22$$

The distance to the point of turning is found by multiplying the actual ground speed out (EP_1) by the time out: $135 \times 2.36 = 318.6$ mi.

INTERCEPTION

If two craft of any sort so move that the direction or bearing between them remains unchanged, and the distance between them is decreasing,
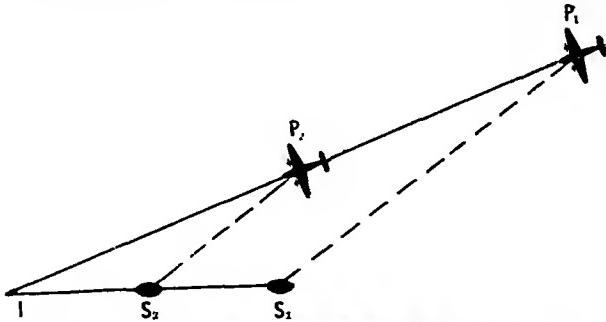
Figure 117.—A constant bearing results in interception.

they will eventually collide, or "intercept." As long as the bearing between them is changing, they will fail to intercept.

In figure 117, S_1 and S_2 are successive positions of a ship at 30-minute intervals, P_1 and P_2 are positions of an airplane at the same moments. It

is seen that the bearing remains constant, and interception will result at the point *I*. This may become clearer if we no longer think of the forward motion of the two craft, but remember only that the direction of the line
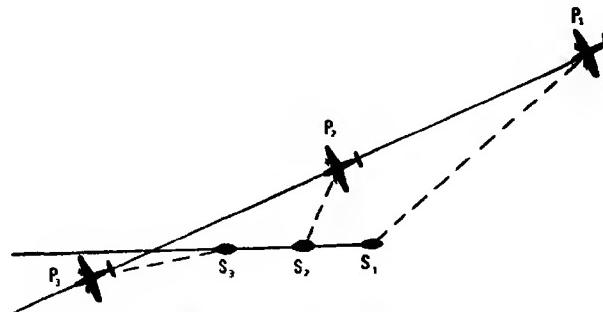
Figure 118.—A changing bearing does not result in interception.

between them remains unchanged while the line itself is growing constantly shorter. The "rate of interception" is the rate at which the airplane approaches the ship along the line of constant bearing.
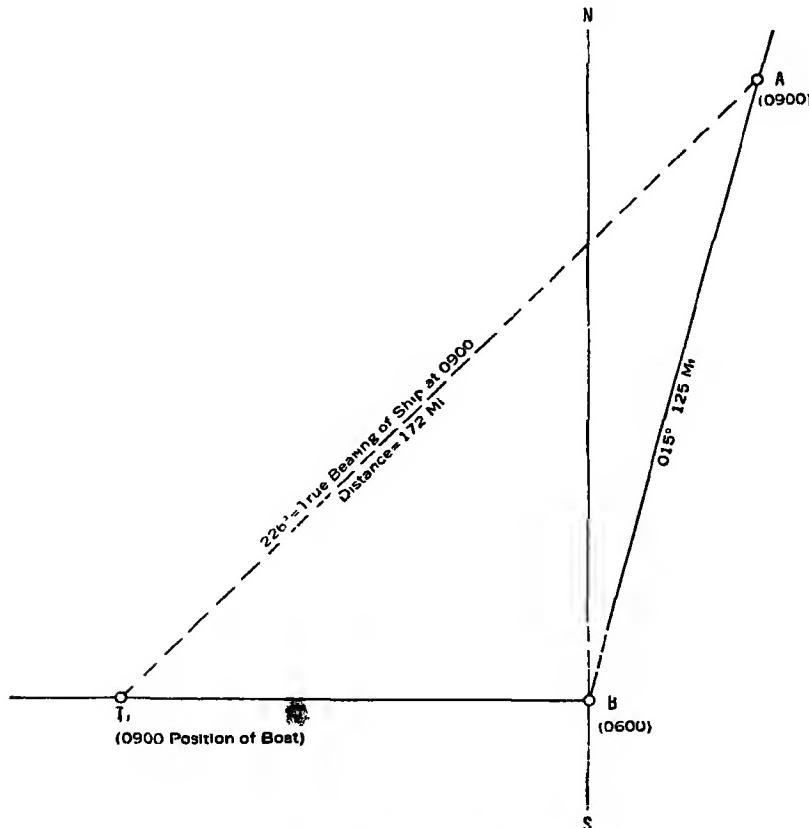
Figure 119.—Condition at start of interception.

This is an example of "relative movement." The whole pattern may be in motion over the earth, but the only motion of interest in this problem is the movement of the airplane relative to the ship, along the line S_1P_1. It is as though a twig were being dragged over the floor, with a fly at one end of the twig and a spider at the other. The movement of the twig is incidental; the only motion of interest to the spider is his own motion along the twig, relative to his supper.

In figure 118 a condition is illustrated in which the bearing does *not* remain unchanged. In this case the aircraft moves progressively ahead and crosses the projected track of the ship well in advance of it. It is apparent that (when viewed from the ship) the airplane, although maintaining a constant speed and direction of flight, will seem to move along its track much more rapidly when near P_2 (close to the ship) than when farther away from the ship (near P_1 and P_1). For the same reason, the direction of the airplane from the ship changes more rapidly near P_2 than near P_1 or P_1.

In order to illustrate all details of the problem, suppose that a boat leaves a harbor B at 0600, on a true course of 270° and at 30 mph; an airplane leaves airport A at 0900 at a true air speed of 115 mph to intercept the ship. A is 125 miles from B, in direction 015°. Wind is 315°, at 33 mph.

Figure 119 shows the relative positions of A and B, and the true bearing and distance of the ship from the airplane at 0900, at the start of the flight to intercept. The true bearing of the ship from the airplane is usually called the "direction of relative movement" *DRM*, and the distance between them is called the "miles of relative movement" *MRM*.
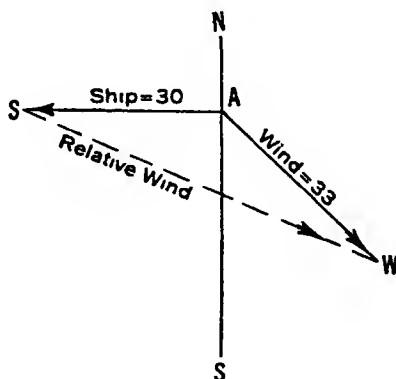
Figure 120. - The "relative wind"

The next step is the determination of the "relative wind." In figure 120 the ship's motion for 1 hour and the wind velocity for 1 hour are both plotted from A. Let us again think of the boat as stationary with A moving backward from the boat, and the wind from 315° through A. The net result would be the same as if the airplane were starting from S with a (relative) wind represented by the broken line SW. With this as a

foundation, it is now possible to construct the "relative wind triangle" shown in figure 121.

If we consider only the relative wind and employ our standard system of letters, it should be labeled EW; accordingly, the unnecessary parts (for the moment) from figure 120 are crossed out in figure 121, and the letter S is changed to "E". Then EP is drawn to represent the true bearing of 226° (DRM) determined in figure 119, which corresponds to the true course in an ordinary wind triangle. WP is drawn equal to the air speed, and represents the true heading to be followed for interception.

Actually, of course, the airplane does not begin its flight from S, even though this point was renamed as "E" in figure 121. It must still begin its
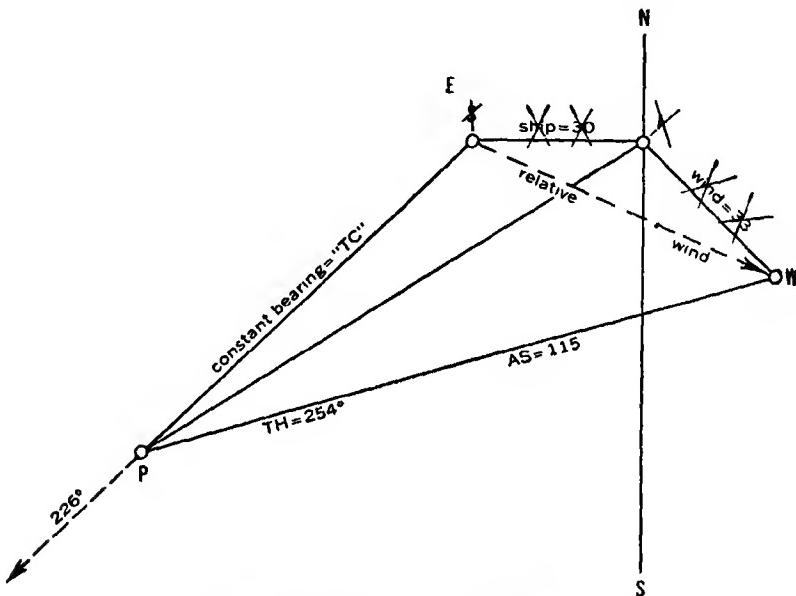
Figure 121 —The "relative wind triangle."

flight from airport A, which is therefore lettered as E in figure 122; this figure shows the complete construction required, with the various parts appropriately labeled. In view of the preceding discussion little further explanation of figure 122 is considered necessary, but it should be carefully studied and thoroughly understood. It is simply the familiar wind triangle EWP, combined with the relative movement triangle ESP.

Since the MRM, or distance (AT_1, fig. 119), is 172 miles, and the SRM, or speed of relative movement (rate at which the airplane approaches the ship; SP, fig. 122) is 80 mph, the time required for interception is $172 \div 80 = 2.15$ hrs., or 2:09:00.

While a number of illustrations have been used in explaining the principles involved, in practice only one diagram need be drawn, in which figures 119 and 122 would be combined. In such a combined drawing E (fig. 122) would be considered as A, and B and T_1 could be plotted with respect to E in order to obtain the relative bearing and distance as in figure

119. This portion of the combined figure may be at a different scale from the remainder of the figure, if desired.
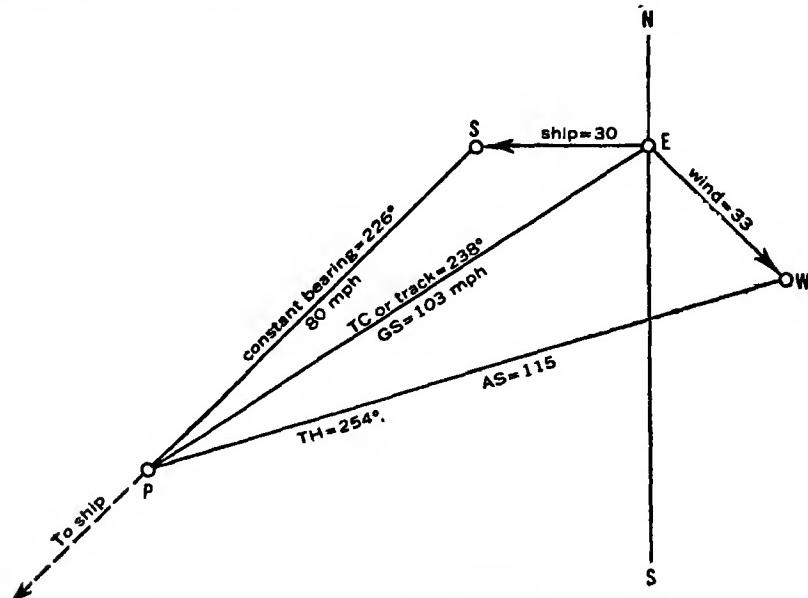
Figure 122. Graphic solution of interception problem.

Using the standard notation, the significance of the following letters will always be as indicated:

In relative movement plot:

E = earth (point of origin)
P = plane
S = ship
EP = true course and ground speed of airplane
ES = ship's course and speed
SP = direction of relative movement (DRM), and speed of relative movement (SRM).

In geographic plot:

A = aircraft's base (usually at start of interception)
T = ship's position at time when interception starts
AT = true bearing (DRM), and distance (MRM) of ship from plane.

Note that A, T, and AT are not properly part of the 1-hour relative movement plot (fig. 122), but are part of the geographic plot (fig. 119).

TRACKING

This is primarily the problem of navigators or pilots in a squadron who are not responsible for the determination of a course or heading to be flown, but who must keep an accurate record of the track made good and of the position at any given moment. This is necessary in order to be able

to set a new course independently if made necessary by enemy action or other emergency. As long as a complete and accurate knowledge of compass heading, variation, deviation, time, and wind is kept, this is one of the simplest problems.

As illustrated in figure 123, a squadron flies the following compass headings between bases A and B, at a true air speed of 140 mph:

Leg No.	CH	Time begun	Time on leg	Time elapsed	TH
1	288°	0930	0:29:00	0:29:00	300°
2	333°	0959	0:09:00	0:38:00	345°
3	268°	1008	0:24:00	1:02:00	280°
4	217°	1032	0:30:00	1:32:00	229°

The compass deviation on each of the above headings is 3° W, and magnetic variation in the area averages 15° E, resulting in the true headings shown above. Throughout the flight the wind is 300° and 20 mph.
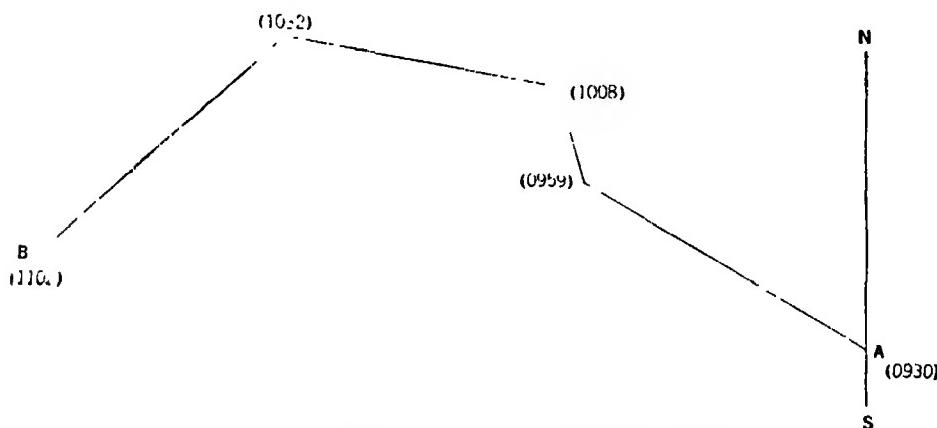
Figure 123 —Tracking plotting compass headings and air distances

The successive true headings are plotted on the chart as though they were courses (see p. 120), without regard for wind effect, and the time of each change of heading is noted, as in figure 123. At any time during flight, in order to find the position reached, it is only necessary to plot the no-wind position reached and then to apply the wind effect for the total time elapsed to that moment.

For example (fig. 124) on the first leg of the above flight there is a head wind of 20 mph. The wind direction is plotted from the no-wind position for 0959, for a distance equal to a force of 20 mph acting for 29 minutes—a little less than 10 miles. The actual position reached, then, is indicated by a.

Similarly, the wind direction and force for the 1008, 1032, and 1102 positions of the airplane are applied in turn, and the points so obtained are connected, resulting in the track indicated by the broken line. If the

position at 1047 were required, the no-wind position at that time is determined as at *b* and the wind effect for the total elapsed time of 01:17:00 is applied, fixing the position at *c*. If an independent fix is obtained at any given time (by landmark, radio, or celestial observations), the wind force and direction can be checked by plotting the no-wind position for the same time; a line from that position to the fix established represents the wind effect for the time elapsed.

In the problem illustrated in figures 123 and 124, although all headings were to be plotted as courses (with the mid-course meridians) they were
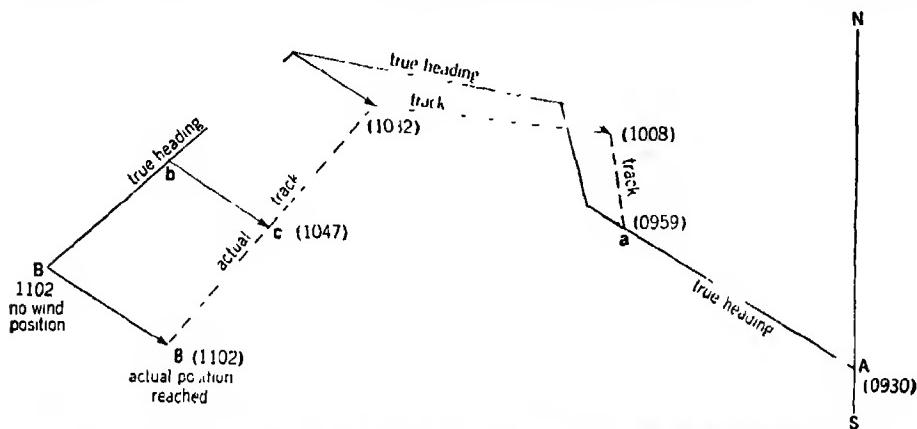
Figure 124.—Determining track and position reached by plotting wind effect for elapsed time intervals.

plotted with reference to the initial meridian *NS*. The maximum resulting error on this account in the final position reached is as follows for the three principal Lambert projection bands:

$$0° - 25° — 0.5 \text{ mi.}$$
$$25° - 50° — 2.3 \text{ mi.}$$
$$50° - 75° — 8.3 \text{ mi.}$$

The total error in each case, in degrees, is equal to half the difference of longitude between the starting point and the farthest point reached, multiplied by the convergence per degree of longitude (see p. 47).

To illustrate further, the problem was positioned at one of the training areas in the southwestern United States. The direct distance between *A* and *B* is 146 miles, covering approximately 2° 30′ of longitude. The error, then, is about $1.25 \times .631 = 0°8$; this angular error amounts to a little less than 2 miles in a distance of 146. In latitudes where errors from this source may be considered excessive, it is simple to estimate the longitude covered on each leg (see p. 121) and to plot the no-wind headings as courses, with the mid-course meridians. In this case, the results obtained are precise, so far as the chart work is concerned.

Where the distance on each leg is short, as in the problem just given, the best and most practical results are obtained by plotting the track directly on the chart, using the meridian nearest the beginning of each leg. With this method, of course, a chart is soon used up, but one primary our-

pose of charts is to serve as suitable bases for the plotting of navigational work; they should be considered as expendable, and replaced as frequently as necessary. In most cases, this will have the added advantage of getting the latest revised charts in the hands of pilots without undue delay.

For many of the special problems of dead reckoning, plotting boards (see Chapter VIII) or plotting charts based on an approximate Mercator projection will be found very convenient. While not precise, the results obtained with these devices are of practical accuracy and generally satisfactory.

QUESTIONS

1. What is meant by climb and descent problems?

2. How is the true air speed usually determined on climb and descent problems? How should it be determined when cruising?

3. What is meant by the "point of let-down"? By the "point of breakthrough"?

4. When conditions of flight will not permit more accurate methods, what is the approximate allowance for the rate of climb and rate of descent?

5. If a pilot finds he has drifted 5° off course to the right, will a correction of 5° to the left return him to his intended track? If not, what correction should he make? (Hint: what wind direction and velocity might have caused a right drift of 5°?)

6. Describe the determination of wind direction and velocity by the double-drift method.

7. What is meant by radius of action?

8. State the basic formula for finding the time to turn (t_o) when the GS_o, GS_b, and total time available are known.

9. Describe a method by which the radius of action per hour of flying time available may be determined graphically.

10. Is the radius of action ever increased by wind effect?

11. What is meant by a "Howgozit" chart?

12. What similarity is there between an alternate airport problem and flight to and from a moving aircraft carrier?

13. What is meant by a "collision course"?

14. What condition is necessary for interception in the least possible time?

15. In accordance with the standard system of lettering, what is the significance of each of the following: S; P; A; T; EP; ES; SP; AT; SRM; DRM; MRM?

16. What is meant by "tracking," and when might it be useful?

17. How can one determine the error resulting when a course is plotted with the initial meridian instead of the mid-course meridian?

PROBLEMS

Instead of working out further "examples" for the student, it was thought better to provide additional problems for the student to work for

himself. The answers are given, to the nearest mile or the nearest degree, as a check on the results obtained. In all problems, compass deviation is assumed to be as in figure 54.

1. An airplane leaves from airport *A*, elevation 1800 feet, to cruise at 7,000 feet; R/C 500 feet at 125 mph; TC 100°; average wind on climb 330° at 30 mph; magnetic variation 3° W.,

Find: time on climb   = 0:10:24
CH on climb   = 093°
distance made good
during climb   = 27 mi.

2. Continuing problem 1, elevation of airport *B* at destination is 1250 feet, ceiling 700 feet; R/D 500 feet at 120 mph; average wind 240° at 22 mph; magnetic variation 2° W.,

Find: time on descent   = 0:10:06
CH on descent   = 107°
distance made good
during descent   = 22 mi.

3. Continuing problems 1 and 2, with wind 270° and 28 mph, and temperature 10° F. at pressure alt. of 7,000 feet, indicated AS 160 mph, magnetic variation 3° W., and total distance 375 mi.,

Find: true AS on cruise   = 174 mph
GS   = 201 mph
CH on cruise   = 106°
time on cruise   = 1:37:00
time from *A* to point of let-down = 1:47:24
time from *A* to break-through   = 1:57:30

4. The TC from *A* to *B* is 167°, distance 320 miles, true air speed 135 mph, magnetic variation 5° E., compass deviation as in figure 54. A TH of 160° was held for 48 minutes, when a fix was obtained over a point *C*, 115 miles from *A*, and about 7 miles to the left of the intended track.

Find: wind   = 25° at 12 mph
CH from *C* to *B*   = 158°
time from *C* to *B* = 1:25:00

5. In problem 4, if it were desired to return to the intended track in line with the wind, and to complete the flight along the route originally intended,

Find: CH to charted route   = 198°
time to charted route   = 0:05:00
CH to make good charted route = 158°

6. With a true AS of 120 mph, a compass heading of 260° was flown, and a drift angle of 10° right was observed; then a compass heading of 170° with a drift angle of 5° right. Find the wind direction and velocity as 149°, 23 mph.

7. With the TC 283°, true AS 140 mph, var. 10° E.. wind 225° at 25 mph, and fuel for 3 hours,

Find: TH₀ = 274°   GS₀ = 125 mph
      THₕ = 112   GSₕ = 152
      radius of action = 206 mi.

8. A ship leaves base *B* at 1110, on TC 202°, at 28 knots. An airplane leaves airport *A* at 1420 to intercept the ship. *A* is 120°, 143 statute miles, from *B*. True AS is 150 mph, wind 135° at 32 knots; var. 5° E.

Find: CH for interception   = 234°
      track to interception   = 252°
      distance from *A* to interception = 161 mi.
      time of interception   = 1528

9. An aircraft carrier is steaming on TC 045° at 22 knots. A pilot is instructed to fly a TC of 085° as far as possible and still return to carrier in 2:30:00. True AS 140 knots, wind 285° at 30 knots; var. 10° W.

Find: time to turn = 1:07:00
      CH₀   = 91°
      distance out = 189 mi.
      CHₕ   = 289°
      distance back = 152 mi.

10. In the preceding problem assume that all other data remained the same, but that the pilot was required to make good a *relative* true course of 085° (that is, to maintain constantly a true bearing of 085° with respect to the moving carrier). Then,

Find: time to turn = 1:08:42
      CH₀   = 085°
      distance out = 191 mi.
      CHₕ   = 284°
      distance back = 150 mi.

11. A pilot leaves base *A* and scouts on the compass headings, indicated below, at true AS 145 knots; wind 250° at 28 knots; var. 18° E.; dev. as in figure 54:

	GIVEN			FIND	
CH	Time on leg	Elapsed time		TC (Track)	Distance (naut. mi.)
°				°	
029	0 31·30	------		050	90
065	0 26 00	0 57.30		080	75
133	0 37 30	1 35.00		140	95
232	1 09 10	2 44 10		250	135
276	0 43 00	3 27 10		303	91

Find also: farthest point reached is 091° true, 203 nautical miles from *A;* flight ends at starting point (base *A*).

Chapter VIII.—AIR NAVIGATION COMPUTERS

FUNCTION AND USEFULNESS

All computers intended for serious navigational work serve two general purposes:

1. The slide rule side is used for all problems involving multiplication, division, and proportion (such as time-speed-distance relations, fuel consumption, air speed corrections, and radius of action equations); and

2. The wind triangle side is used for the solution of problems of this nature by inspection, without the necessity for graphic methods.

With respect to the slide rule side, there is very little choice between the many computers available. Some are very accurately constructed; others may be more legible, while still others are easily adjusted with one hand. One may have a special feature, usually at the expense of some other desirable item—but most of them are of the same general form and are used in much the same way.

The construction of wind triangles and other graphic plots in flight is often impractical, and is time consuming at best. The wind triangle
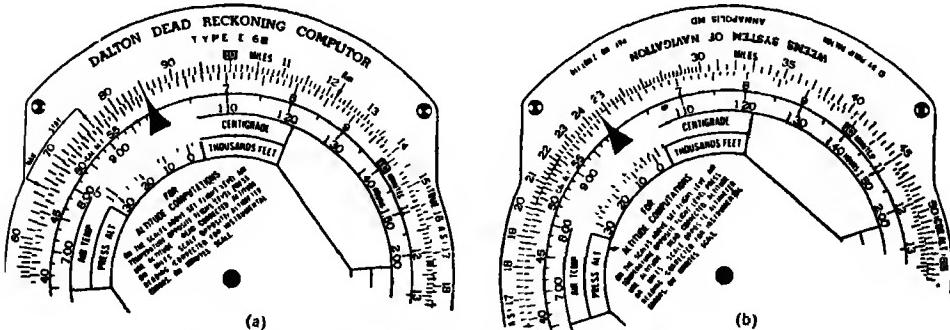
Figure 125—Importance of accurate readings of the computer.

side of a computer usually represents the inventor's idea of the most convenient way of furnishing the pilot with the various parts of a wind triangle. When these parts have been properly adjusted, "with a simple twist of the wrist," the answers may be read from the computer by inspection. In a few instances this part of the computer is strictly mathematical, and appears to have no relationship to the graphic plot.

In general, that computer is to be preferred on which the individual pilot can see most clearly the component parts of the wind triangle. Any good computer, in the hands of one thoroughly familiar with it, will yield

accurate results so quickly that it seems "like magic." Having selected your computer, then, study it and use it until you are thoroughly familiar with it—so familiar that a wrong setting is almost impossible.

As part of your computer practice, learn to take readings from it that are both complete and accurate. For example, the heavy arrow-head index in figure 125 (*a*) does not point to 805, but to 850. In figure 125 (*b*) the index points to 246, not 243. Careless readings of this sort are a most frequent cause of trouble.

The graphic construction described in the preceding chapters is *fundamental, and must be thoroughly understood before taking up the computer.* In fact, any effort to use a computer without this thorough understanding is a waste of time, and is almost certain to produce the wrong answers.

THE SLIDE RULE SIDE

DESCRIPTION

This consists primarily of a circular disk rotating over a base scale. While there is as yet no fixed rule, and few computers are actually labeled, it has become quite customary to call the outer one "scale *A*," and
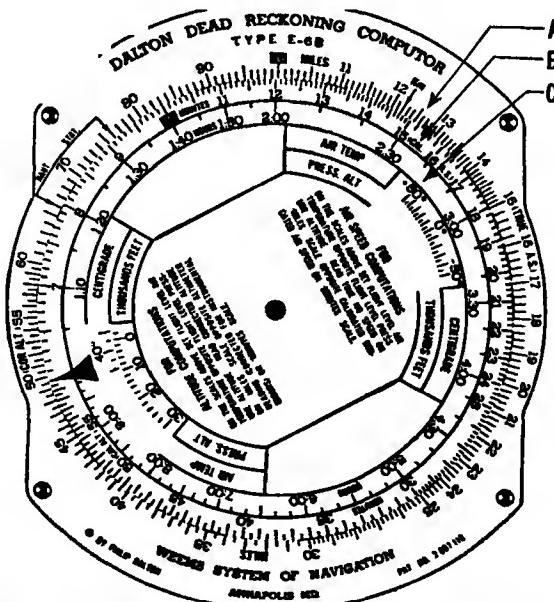
Figure 126 —Multiplication and division with the slide rule side.

the inner smaller one "scale *B*." In figure 126 they have been so indicated and for convenience they will always be so referred to in this text.

All numbers on disk *A* and on the outer scale of disk *B* may be regarded as multiples of 10—that is, 25 may be considered as 2.5, 25, 250, or 2500, etc., according to the problem. The word "Minutes" appears on the outer scale of disk *B*, between the figures *30* and *35*; just inside the "minutes scale" is an "hour scale," often referred to as scale *C*. This

scale is for convenience in converting minutes to hours; it has no other purpose on the computers. For example, just below *30* the figures *5:00* appear, 300 minutes being equal to 5 hours.

THE UNIT-INDEX

On scale *B* the number 10 is printed within a black square, for emphasis. This is referred to as the "unit-index" (since 10 may also be read as 1.0), and is used with scales *A* and *B* in all problems of multiplication and division.

To multiply one number by another, rotate disk *B* until the unit index is opposite one of the numbers (the multiplicand) on disk *A*; the product is then read from disk *A*, opposite the other of the two numbers (the multiplier) on disk *B*. For example, in figure 126 the number 83 (on disk *A*, opposite the unit index) is to be multiplied by 20; opposite 20 on disk *B*, the product is read from disk *A* as 1660. Note that with the unit index at 83, at this one setting the product of 83 with *any* number may be read on disk *A* opposite the number on disk *B*: $83 \times 15 = 1245$; $83 \times 35 = 2905$; $83 \times 66 = 5478$; $83 \times 8.3 = 688.9$; and so on. (NOTE: Because of the mechanical difficulties in preparing illustrations of this sort, not all these results are precisely indicated in the figures.)

It is often possible to get more precise results by combining a little mental arithmetic with the use of the computer. In multiplying 83×66, the product cannot be read closer than "about 5475." By simple arithmetic, however, it is obvious that the last figure should be 8, and the result is therefore read as 5478. In the practice of navigation products involving more than three figures are seldom required, and these may be read to the nearest whole number with satisfactory accuracy.

To divide, the multiplication process is simply reversed. The dividend on disk *A* is placed above the divisor on disk *B*, and the unit index on disk *B* will then point to the quotient on disk *A*. In figure 126, $688.9 \div 8.3 = 83$; $5478 \div 66 = 83$; $2905 \div 35 = 83$; and $1245 \div 15 = 83$.

Problems in percentage are in reality problems in multiplication. Referring again to figure 126, 83 percent of $15 = 12.45$; 83 percent of $35 = 29.05$; 83 percent of $66 = 54.78$; and 83 percent of $8.3 = 6.89$. Another method of working percentage problems is to place the required percent on disk *B* beneath 100 on disk *A*; when this is done, the corresponding percentage of any number on disk *A* may be read directly beneath it on disk *B*.

The processes of multiplying and dividing should be learned thoroughly by practicing with a few familiar quantities, such as 3×33; $99 \div 3$; $33 \div 3$; and 5×12.

THE 60-INDEX

Where the number 6 (or 60) should appear on the *B* scale there is an arrow-head which will be referred to as the "60-index," which is much used in problems involving miles per hour.

In figure 128, a light airplane with fresh head winds was making good a ground speed of only 64 mph. With 64 miles on the *A* scale set against the 60-index (that is, against 60 minutes) on *B*, then the number of miles made good in any other number of minutes may be read from the *A* scale adjacent to the time interval in question, without changing the setting: 6 mi. in 5.6 min.; 8.5 mi. in 8 min.; 128 mi. in 120 min. (or 2:00 hrs.).

With a ground speed of 145 mph, the following time-and-distance relations may be noted. The student should check these values for himself.

10 mi. in 4.1 min.	50 mi. in 20.6 min.	
14 mi. in 5.8 min.	72.5 mi. in 30.0 min.	
25 mi. in 10.3 min.	290.0 mi. in 120.0 min. (2:00:00)	
35 mi. in 14.5 min.	500.0 mi. in 206.0 min. (3:26:00)	

The reverse problem is also of interest. A pilot passing over a landmark 12.8 miles from his airport just 12 minutes after taking off needs only to set one against the other to read his ground speed of 64 mph; see figure 128. Or passing a landmark 35 miles from base after 14.5 minutes of flying, his ground speed is at once read as 145 mph.

By setting the 60-index to the correct ground speed, the miles per minute made good may be read at the unit index. This should be obvious, since the unit index represents 1 minute, and with the computer correctly set the number of miles made good in any time interval may be read against the time interval in question. With a ground speed of 64 mph, 1.06 miles will be made good in 1 minute; with ground speed 145, 2.4 miles per minute.

THE 36-INDEX

For calibrating air speed meters and for timed approach in instrument landing and in related problems, the distance made good per second, or the seconds required to make good a short distance are important. For this purpose a red or blue index should be drawn at the division for 36 on the *B* scale, as shown in figure 127. With the "36-index" at the ground speed in mph, the number of seconds to make good any given distance may be read from the *B* scale adjacent to the distance on the *A* scale.

To illustrate, suppose that an instrument approach is being made at a ground speed of 105 mph, and the distance from the range station to the airport is 2.4 miles. To find the number of seconds required to reach the airport, set the 36-index against 105, and under 2.4 (24) on the *A* scale read 82.5 seconds, or 0:01:22.5. One mile will be made good in a little more than 34 seconds; see figure 127.

As a further example, an airplane is flown over a 2-mile speed course in 42 seconds. By bringing 42 on the *B* scale adjacent to 2 (20) on the *A* scale, the ground speed is read opposite the 36-index as 171 mph.

The 36-index can be used in this way, of course, because one second is the 3600th part of 60 minutes. In all problems, knowing the general
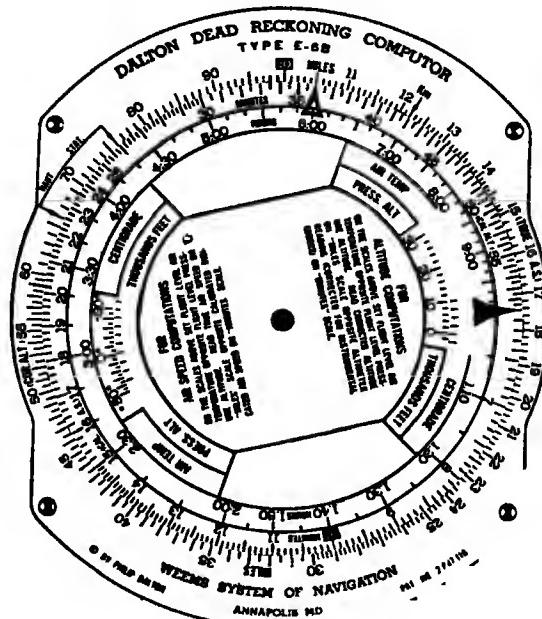
Figure 127.—Distance per second, using the 36-index.

relationship of the various quantities the placing of the decimal point is most easily determined by mental arithmetic.

NAUTICAL MILES—STATUTE MILES—KILOMETERS

For a few special problems, the processes have been made even simpler. For example, 1 nautical mile = 1.15 statute mile, and 1 kilometer (km) = 0.62 statute mile. It is not necessary to remember these numbers, however, nor to use them consciously in converting any one of these quantities to another. Near 70 on the *A* scale are arrows labeled "naut." and "stat."; near 12 is an arrow labeled "km." By placing any number on disk *B* against the appropriate arrow, the equivalent number of other units is read from disk *B* adjacent to the other arrows. In figure 126, 91.5 statute miles = 79.5 nautical miles = 147 kilometers.

TRUE AIR SPEED

The true air speed may be found readily from the scale marked "For Air Speed Computations"; see figure 128. The indicated air speed, of course, must be corrected for instrumental and installation errors, the corrected reading being known as the "calibrated air speed." The temperature observed in flight is set opposite the pressure altitude of flight, after which the true air speed is read from disk *A* adjacent to the calibrated air speed on disk *B*. To help prevent any error here, the words

"True A.S." are found near the number 16 on disk A, and "Cal. A.S." near 16 on disk B. The "pressure altitude" is the altitude indicated when the barometric scale of the altimeter is set to 29.92 inches.

Referring to figure 128, while flying at a pressure altitude of 5,000 feet a temperature of 0° centigrade was recorded. Setting 0° C. against
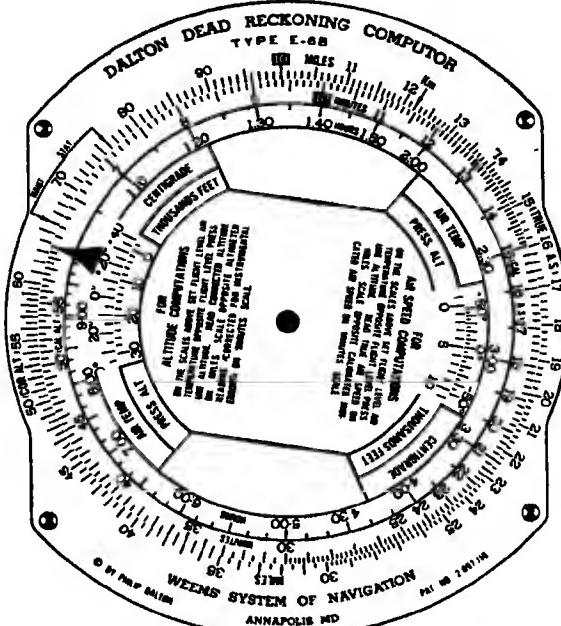
Figure 128.—Finding the true air speed.

5, the true air speed of 192 mph is read adjacent to the calibrated air speed of 180. Or with a temperature of −20° C. at 7,000 feet, a true air speed of 130 miles is read adjacent to the calibrated air speed of 122.

CENTIGRADE—FAHRENHEIT

On some computers the temperature scale is in terms of degrees centigrade; on others the Fahrenheit scale is used. Care should be taken to avoid mistakes due to using the wrong temperature scale. Figure 129 shows the relation between these scales, with rules for their conversion. If the relation shown in bold-face type is kept in mind, it should always be possible to remember (or to reconstruct) the procedure.

The indicated multiplication and division can be readily performed with a computer, but again there is a short cut. If the required addition or subtraction of 32° is first taken care of, the relation between F.° and C.° is always in the ratio of 1.8 to 1.0 (since 180° F. = 100° C.; see fig. 129). On the computer, if the number 18 on disk A is set above the unit index on disk B, then all numbers on disk A are in the same proportion (1.8:1.0) to the adjacent numbers on disk B—that is, having taken care of adding or subtracting the 32°, the Fahrenheit temperature on disk A

CENTIGRADE   FAHRENHEIT

Water boils 100° 212° Water boils

To convert to Fahrenheit   To convert to Centigrade

(a) If above freezing   (a) If above freezing
    F° = (C° x 1 8) + 32°   C° = (F° − 32°) ÷ 1.8

(b) If below freezing   (b) If below freezing—
    F° = 32° − (C° x 1.8)   −C° = (32° − F°) ÷ 1.8

Examples: Examples:

(a) 30°C x 1.8 = 54°   (a) 50° F − 32° = 18°
    30°C $\underline{+32°}$ 18° ÷ 1.8 = 10°C
              = 86°F   50°F = 10°C
(b) − 20° x 1 8 = −36°   32°   (b) −4°F = 32° − (−4°) = 36°
                         $\underline{−36}$ 36° ÷ 1.8 = 20°C
    − 20°C   =.   − 4°F   −4°F = −20°C

Water Freezes 0° 32° Water Freezes
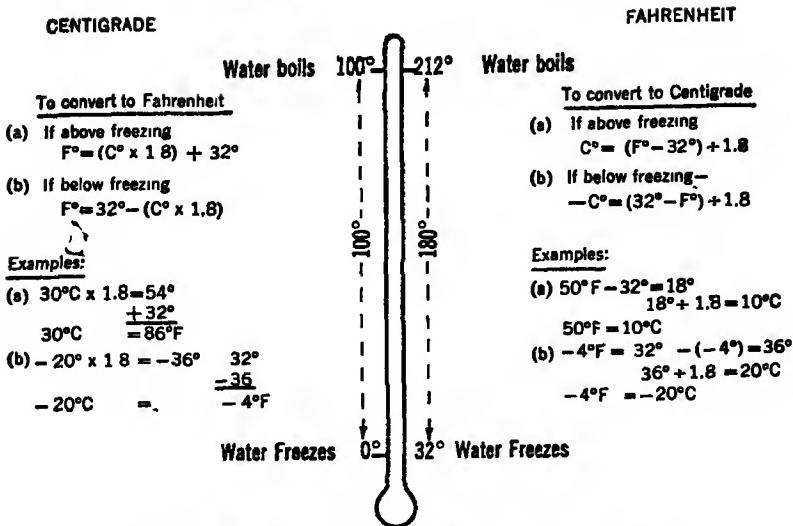
Figure 129.—Relation between centigrade and Fahrenheit scales

is always adjacent to the corresponding centigrade temperature on disk *B*.

ALTIMETER CORRECTION

Provision is usually made for the correction of altimeter errors. In figure 130 a scale "For Altitude Computations" is shown. As explained on the computer, the temperature observed at the flight level is set ad-
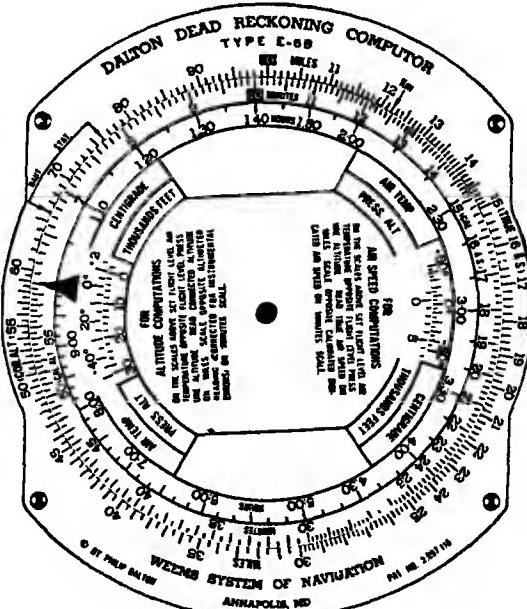
Figure 130.—Finding the correct altitude.

Jacent to the calibrated pressure altitude, after which the corrected altitude is read from disk *A* adjacent to the calibrated altitude on disk *B*.

Note the words "Cor. Alt." near the number 50 on disk A, and "Cal. Alt." near 50 on disk B, to insure proper use of the computer.

On a certain flight, when the indicated altitude was 5,100 feet, a pressure altitude of 5,000 feet and a temperature of 0° C were observed. In figure 130, with the pressure altitude set against the observed temperature, the correct altitude of 5,000 feet is found on disk A opposite the indicated altitude of 5,100 on disk B. It should scarcely be necessary to point out that figures 128 and 130 do not represent solutions for one setting only, but rather for a series of settings. For example, figure 130 represents the correct setting for a pressure altitude of 10,000 feet and a temperature of —10° C; for 20,000 feet and —29° C; for 25,000 feet and —39° C, and so on.

While the altitude found in this way is as nearly correct as can ordinarily be obtained, it should be recognized that even this is, only approximate, and with limited visibility a good margin of safety should always be allowed.

A more accurate determination of altitude can be obtained when the average temperature and average height of the air column between the airplane and the ground are used. That is, a pilot flying at an indicated altitude of 9,800 feet observes a pressure altitude of 10,000 feet and a temperature of —17° C; the ground temperature reported at an airport beneath him, which is 2,500 feet above sea level, is + 5° C. The average temperature of the air column is —6°, and the average altitude is (9,800 + 2,500) ÷ 2, or 6,150 feet; setting the computer for these data the corrected altitude of 9,500 feet is read on scale A opposite the indicated altitude on scale B. By way of comparison, if the temperature at flight level (—17°) had been set against the pressure altitude of flight (10,000) the corrected altitude would have been found as 9,350 feet.

RADIUS OF ACTION

The formula for radius of action was given in the preceding chapter as,

$$t_o = T \frac{GS_b}{GS_o + GS_b}$$

By mathematical development, this formula may also be expressed as a proportion, as follows:

$$\frac{GS_o + GS_b}{T} = \frac{GS_t}{t_o}$$

If the first numerator is set on the A scale against the denominator on the B scale (for minutes) or the C scale (for hours), then adjacent to the second numerator on the A scale may be read the time to turn on the B scale (or C scale). The proper setting is indicated by adding the letter of the scale on which each quantity is to be set, in parenthesis, after each term of the formula:

$$\frac{(GS_a + GS_b) \ (A)}{T \ (B) \text{ or } (C)} = \frac{GS_b \ (A)}{t_o \ (B) \text{ or } (C)}$$

To illustrate, suppose $GS_a = 165$, $GS_b = 195$, $T = 4{:}30{:}00$; find t_o. Substituting in the above,

$$\frac{360 \ (A)}{4{:}30 \ (C)} = \frac{195 \ (A)}{t_o \ (C)}; \qquad t_o = 2{:}26{:}00$$

THE WIND TRIANGLE SIDE
DESCRIPTION

This side of the computer is simply a convenient means of furnishing pilots with the various parts of the wind triangle so that by easy adjustment the desired data may be determined by inspection.

As previously mentioned, it is useless to bother with a computer at all until the graphic solutions are fully understood and can be obtained without hesitation. At first the student may wish to draw the parts of the wind triangles on the computer, but for one thoroughly familiar with the problem it will be easy to visualize the graphic solution on the computer from a few circled dots, without drawing any lines. The lines and arcs of the computer, when properly adjusted, will supply the missing line-work between the circled dots.

In the preceding chapters a number of problems were solved graphically. The same problems will now be taken up in turn, and solved by means of computers, with the solution by computer and the graphic solution side by side, to show how the graphic plot is reproduced by the computer.

In figure 131 the problem of figure 84 is shown set up on three computers. The first is quite inexpensive, and represents clearly the entire wind triangle. It is typical of several which are very satisfactory for the routine problems of the private flier, but cannot be used for some of the more complex problems of modern air navigation. The other two can be used for almost any problem that may arise, and are generally similar in use; both have proved popular, although other computers are also rather widely used. The working size of the plotting disks (inside the compass roses) is about 4 inches in diameter, which is satisfactory for most problems.

The Mark 3A plotting board shown in figure 138 is essentially the same as these two computers, except that the plotting disk is about 12 inches in diameter, and more accurate results can be obtained from the larger-scale plots. This applies more particularly to alternate airport and interception problems, and others in which the geographic plot covers an extensive area.

On the Mk. VII and Mk. 3A, usually the complete triangle is drawn or visualized, but the length of one side of the triangle can only be obtained by addition or subtraction. On the E–6B, the lower point of the

triangle is missing; the true heading and the track are ordinarily found by adding or subtracting the wind correction or drift angles, but all other parts are obtained by direct reading, which is easier for many pilots.

One of the first and obvious things to be learned in connection with the Mk. VII and the Mk. 3A is that every grid line parallel to the grid line through the center has the same direction as the central line. That is, when the Mk. VII has been set with the "Track Index" at 097° (fig. 131), not only is the direction of the red center line 097° but all other red grid lines parallel to it, or any pencil lines drawn between them and parallel to them, have the same direction of 097°. Every red grid line perpendicular to the track index line has the same direction of 187° (or 007°).

TO OBTAIN TRACK AND GROUND SPEED

In the problem of figure 84, reproduced in figure 131, an airplane was headed due east from E at a true air speed of 100 mph, but with wind 20 mph from 315°, arrived in one hour at P, the ground speed represented by EP being 115 mph.

On the first computer the wind triangle of figure 84 is apparent, and the ground speed of 115 is read directly. The track EP is arrived at by adding the drift angle of 7° to the true heading of 090° = 097°.

On the second computer (Mk. VII), the direction and velocity of the wind are first plotted by turning 315° on the compass disk to the "True Heading Index" and marking with circle-and-dot a point 20 miles *below* the center of the disk (since the wind is *from* 315°). The true heading of 090° is then set at the true heading index and the red track-line grid is turned so that P and the true air speed of 100 mph (on the black air speed scale of the base) both lie along the same red grid line. The ground speed is then read from the red ground speed scale as 100 (to the center red cross-line) + 15 (above the center cross-line) = 115 mph, and the track is read from the track index as 097°.

On the third computer (E–6B), the wind is plotted and the true heading of 090° is set as before. The green base grid is then slid into position so that the true air speed of 100 is beneath the small center circle. The ground speed of 115 mph is then read from the position of P between the arcs for 110 and 120 mph, and the drift is read as 7° to the right: 090° + 7° = 097°.
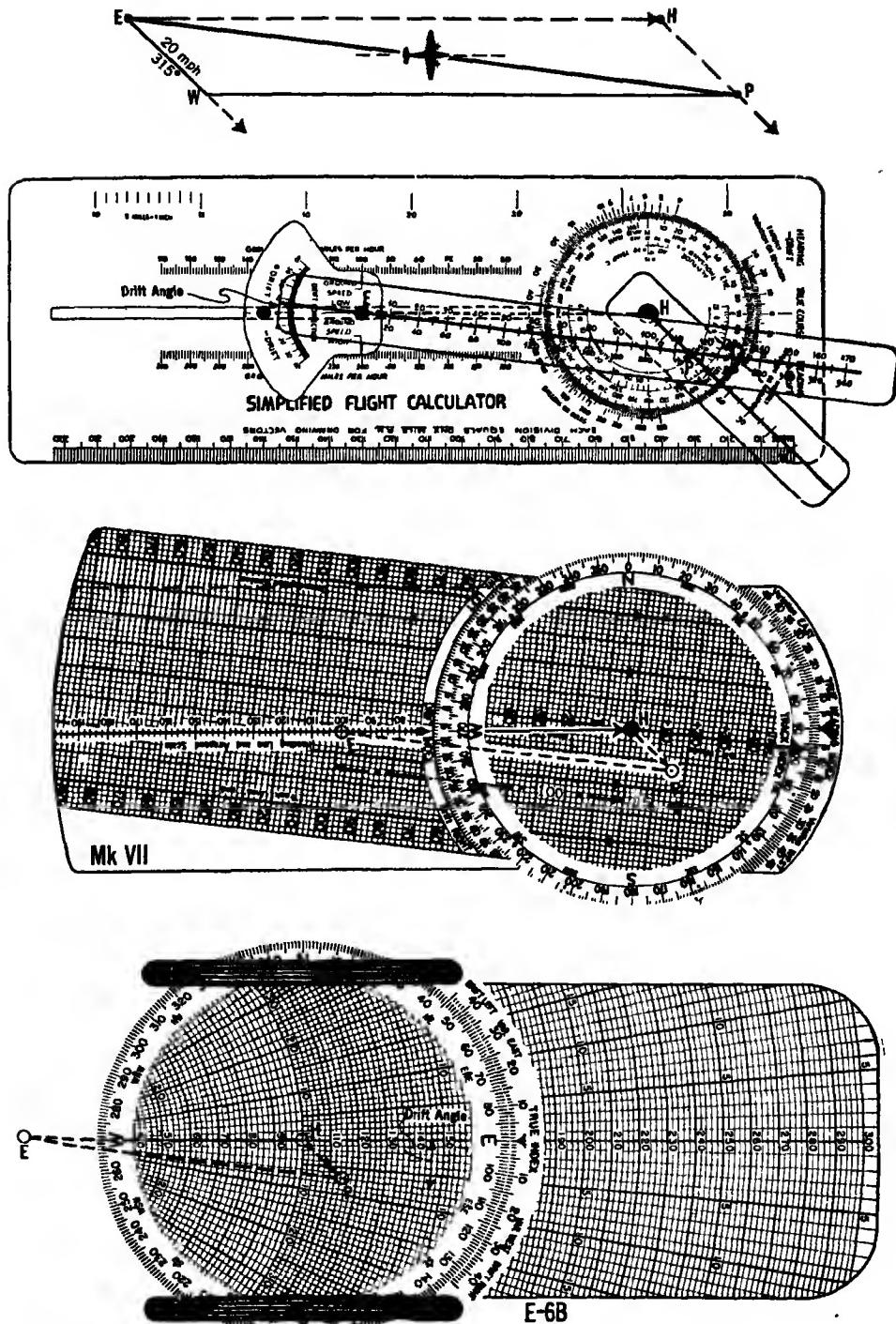
Figure 131.—Drift problems set up on three computers.

TO OBTAIN TRUE HEADING AND GROUND SPEED

Figure 132 shows an airplane making the flight under the conditions of figure 131, except that this time the correct allowance for wind is being made in order to enable the airplane to track the desired true course of 090°. This is the same problem illustrated in figure 86, which is reproduced with the computer settings for easy comparison.

As before, the wind triangle of figure 86 is readily apparent on the first computer. The required heading is obtained by subtracting the "drift" angle of 8° from the intended true course of 090° = 082°, and the ground speed is read directly as 113 mph.

On the Mk. VII the wind is plotted as before. The desired track of 090° is brought to the "track index," then the two parts are turned together until P and the true air speed of 100 mph (on the black air speed scale of the base) both lie along the same red grid line. The true heading required is then read at the "true heading index," and the ground speed is determined as 99 (to the center red cross-line) + 14 (above the center cross-line) = 113 mph.

On the E–6B the wind is plotted as before, except that in this case the 20 mph is laid off above the center, into the wind, since for this problem the wind is to keep pushing the airplane toward the intended track, represented by the center line; the intended track of 090° is next set at the true index. The green base grid is then slid into position, with H over the air speed arc for 100 mph. The ground speed is now read beneath the small center circle as 113 mph, and the true heading is determined as 090° minus the wind correction angle of 8°: 090°—8° = 082°.

In this connection it should be noted that with the Mk. VII the true heading index and the track index always indicate those quantities; with the E–6B the true index may indicate either the heading or the intended true course (track), according to the problem.

When using the center line of the E–6B as the heading, to find the track, the wind vector should be laid off "with the wind" (from the center and away from the direction from which the wind blows); when using the center line as the true course or track, to find the heading, the wind should be laid off "into the wind" (from the center and toward the direction from which the wind blows). Some pilots who have difficulty remembering this rule at first lay off the wind *both* directions from the center; then as soon as the computer is set for the next step it is immediately obvious which of the dots is to be used. With only a little practice, it is so easy to visualize the wind triangle on the E–6B that this should present no difficulty.
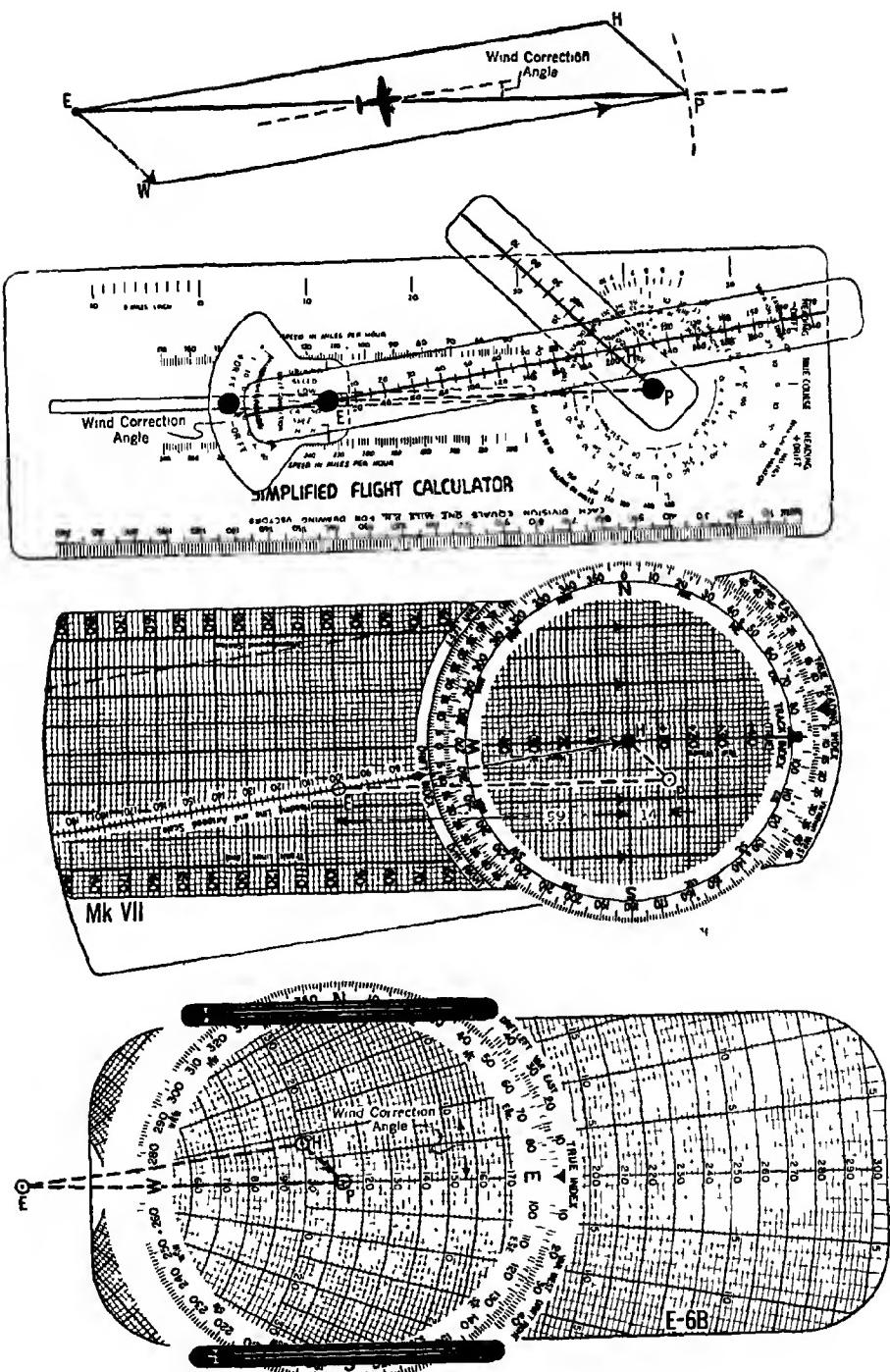
Figure 132.—Allowance for wind set up on three computers.

In figure 133 the problem of figure 98 is shown set up on two of the three computers previously illustrated. In the upper part of the figure there has been added in broken lines the triangle as it appears on the computers; it should be obvious that the two triangles are similar and equal.
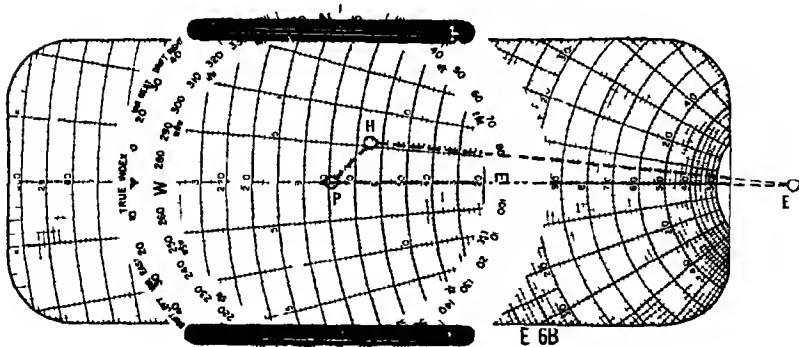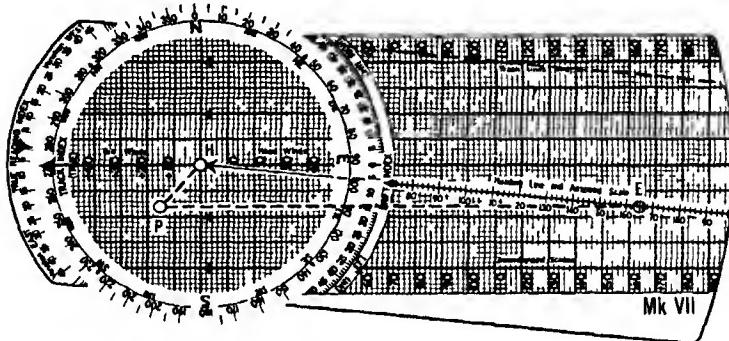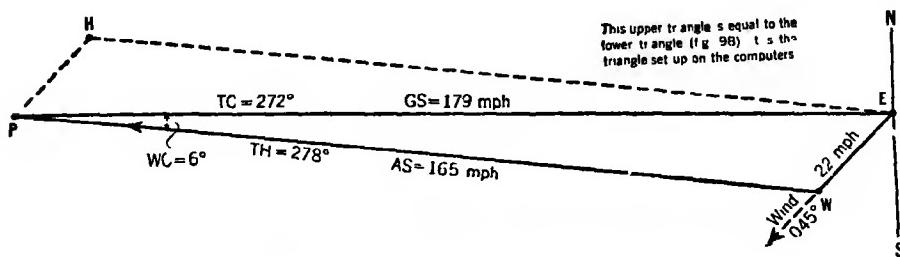
Figure 134 Allowance for wind on the Mark VII and F 6B

On the Mk. VII the wind is plotted; the intended track of 272° is set at the track index; compass disk and grid are turned together until *P* and the true air speed of 165 mph both lie along the same red grid line. The true heading required is then read as 278°, and the ground speed as 164 + 15 = 179 mph.

On the E–6B the wind is plotted and the intended track of 272° is set at the true index; the green base grid is then positioned with H over the air speed arc for 165 mph (between 164 and 166). The ground speed is now read beneath the small center circle as 179 mph, and the true heading is determined as 272° plus the wind correction angle of 6° = 278°.

Most computers of the Mk. VII, E–6B, or Mk. 3A type, incorporate scales of magnetic variation adjacent to the true index. Some navigators find it convenient to draw an additional "magnetic index" arrow at the variation existing in the vicinity of flight. That is, if the variation for a given problem is 8° E., an index arrow is drawn at the corresponding point on the scale, after which magnetic direction may be read at the magnetic index, and the equivalent true directions may be read at the true index, without arithmetic. It will be necessary to erase the magnetic index, of course, and draw in a new one for each change in magnetic variation.

No use is made of the variation scales in the following examples, believing that it is simpler to work always in true directions, and that the application of variation (and deviation) as already explained, is less subject to error.

OFF-COURSE CORRECTIONS

Figure 134 illustrates the computer solution of the problem of figure 103. In the problem, with a true heading of 280°, a fix was obtained after 57 minutes of flight which was 132 miles from starting point and 8 miles to the right of the intended track of 270°. On the Mk. VII, 8 miles is set off to the right of the center, and the red grid is turned until this point and the 132-mile division of the black air speed scale both lie along the same red grid line. The track index is now 3½° to the right · of the true heading index, indicating a track of 273½°; the ground speed has been 132 miles in 57 minutes, or 139 mph. With these data, then, the Mk. VII is set up as in figure 134. The true heading of 280° on the compass disk is brought to the true heading index and held there while the red grid is turned until the track index is at 273½°; the true air speed of 135 mph is then found on the black air speed scale, and it is noted that the red ground speed grid for 134 mph passes through the point. The ground speed was 139 mph, so the red grid line is followed to a point 5 miles beyond the red center cross-line, and the point is marked with circle and dot (134 + 5 = 139). A line from the center to the dot represents the wind direction and velocity; with the center line of the grid directly over the air speed scale, the compass disk is turned until the dot is directly below the center, along the air speed scale, when the direction of the wind is read at the true heading index as 020°, and the velocity as 17 mph.
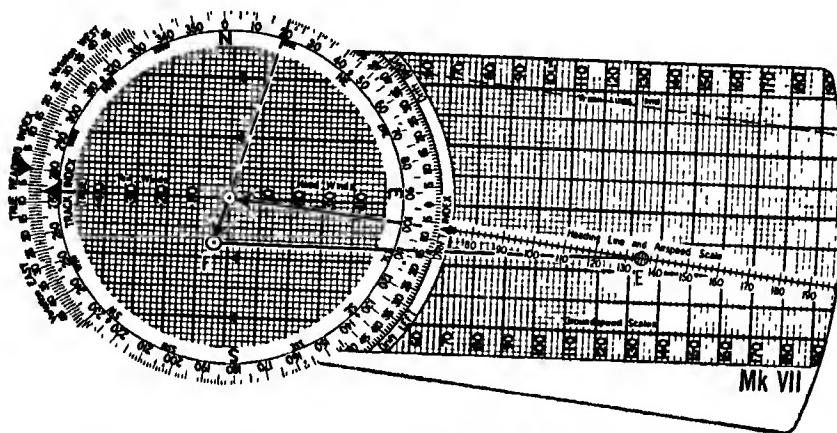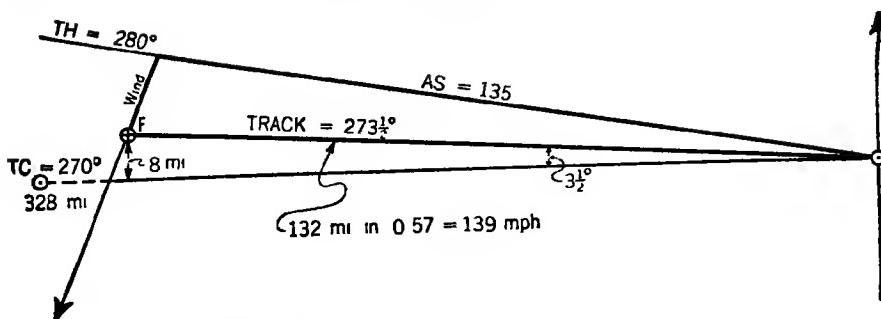
Figure 134.—Determination of wind from off-course errors, using the Mark VII.

Now the compass disk is to be used for a graphic plot of A, B, and the point where the fix was obtained. Bring 270° on the compass disk to the true heading index; then, using a scale of 5 miles to each fine line of the grid, locate A as shown in figure 135 and B 328 miles from A, since B is 270° and 328 miles distant. Next, the fix F is located 132 miles from A and 8 miles to the right of AB; bringing the fix and B along the same red grid line (or equidistant between the same red grid lines) the true course from the fix to B is read at the true heading index as 267°.

With the true air speed and new true course, and the wind direction and velocity known, the computer is set up for the new wind triangle, and a true heading of 274° and ground speed of 141 mph are determined.

The foregoing description sounds rather involved. The entire problem should be set up on the student's own computer, and followed through at least three or four times, until each step becomes natural and logical, when it will be found that the whole solution can be accomplished very quickly.

With the E-6B the details are only slightly different. The true heading of 280° on the compass disk is brought to the true index, and the true air speed of 135 mph is positioned beneath the small center circle.

From figure 103

Fix ⊕

B○   ○A
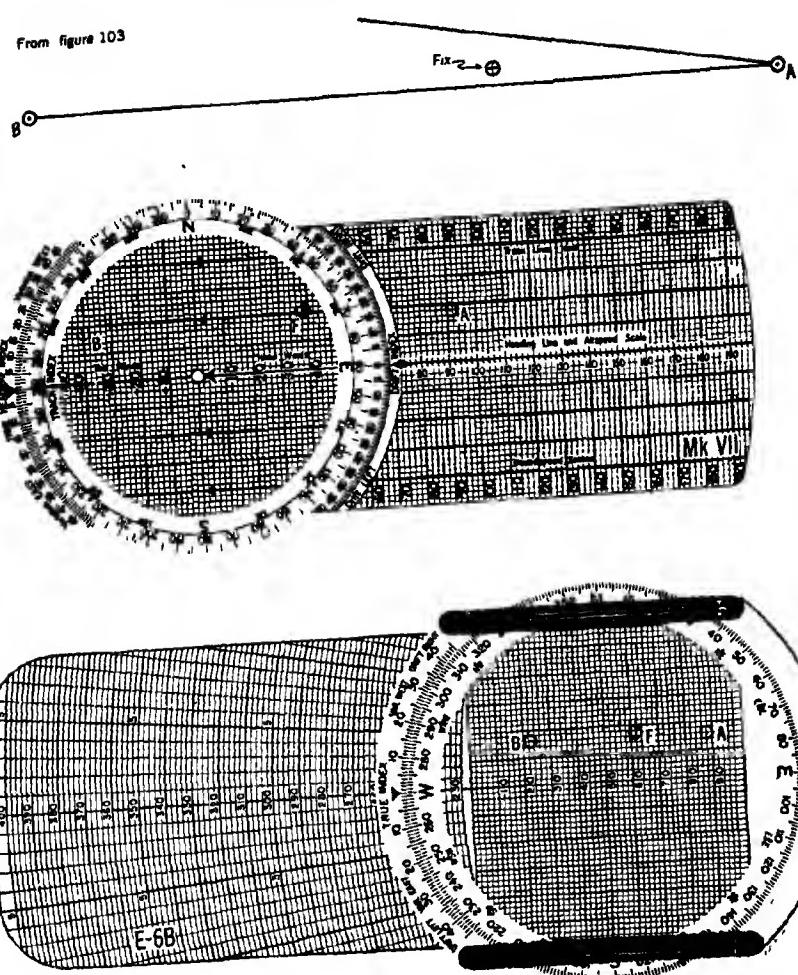
Figure 135.- Using the compass disks of the Mark VII and E-6B for a graphic plot.

The track was determined as 273½°, or 6½° left from the heading; therefore a circled dot is placed along the line corresponding to 6½° left drift at the arc distance corresponding to the ground speed of 139 mph. Then when the dot is brought along the center line, below the center, the wind direction is read at the true index as 020°, and the velocity as 17 mph.

For the next step, when the compass disk is to be used for the graphic plot, the rectangular grid is inserted under the compass disk and the procedure is the same as with the Mk. VII, except that a scale of 10 miles to each fine grid line is used; see figure 135. When the true course from the fix to B has been determined, the final wind triangle is solved as previously described.

DOUBLE DRIFT

The problem of figure 105 is easily set up and visualized on both the Mk. VII and the E-6B. See figure 136. On the Mk. VII the true heading of 045° is brought to the true heading index and held there while the track index is turned 4° to the left; then a short portion of the red grid line passing through the true air speed of 110 on the black air speed scale is penciled in. Next the heading of 315° is set up and the track index turned 8° to the right; again a portion of the red grid line through the true air speed of 110 is penciled in. Finally, the intersection of the two drift lines is turned to the center line, below the center, and the wind direction is read at the true heading index as 197°, the wind velocity as 19 mph. (Note: In fig. 136 the intersection is *above* the center, for easier comparison with fig. 100, and in this case the direction from which the wind is blowing is read at the "Drift Index.")

With the E-6B the procedure is only slightly different. The true air speed of 110 mph is set under the small center circle, the true heading of 045° is brought to the true index, and a portion of the line representing 4° left drift is penciled in. Then the true heading of 315° is set up, and a portion of the line representing 8° right drift is penciled in. Finally, the intersection of the two drift lines is brought along the center line, below the center, and the wind direction is read at the true index as 197°, and the wind velocity is measured from the center to the intersection as 19 mph. (As with the Mk. VII, in fig. 136 the intersection is *above* the center, for easy comparison, and 180° must be added to the 17° at the true index).

RADIUS OF ACTION

An approximate solution of simple radius of action problems can be obtained with one setting of the computer. In figure 137 which illustrates the solution for the problem of figure 111, the triangle for the flight out is set up for the known data, and the wind correction angle of 6° and ground speed of 117 mph are determined.

As already pointed out (p. 112) a wind correction angle to be added for flight in one direction must be subtracted for flight in the opposite direction. This much is precise. Next it is assumed that the ground speed on the reverse heading will be decreased by wind as much as it is increased on the original heading (or vice versa)—that is, if $GS_o = AS$ + effect of wind, $GS_b = AS$ minus the same amount. This is an approximation which is of satisfactory accuracy only if the wind correction angle is not large.
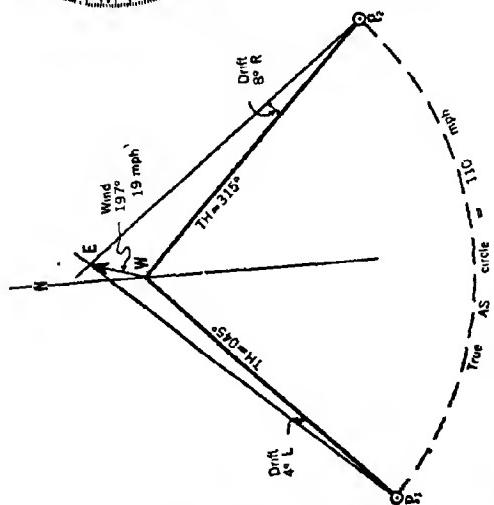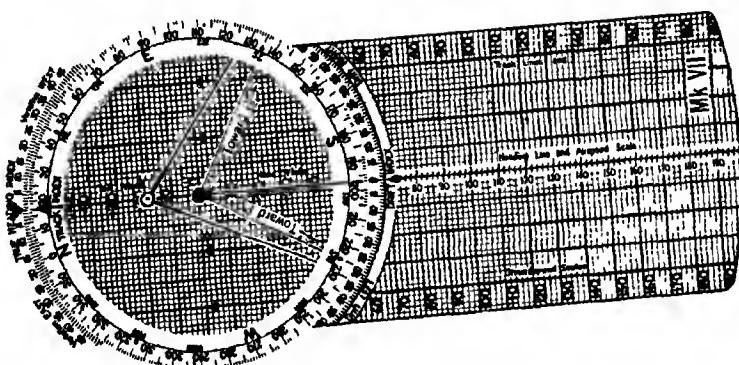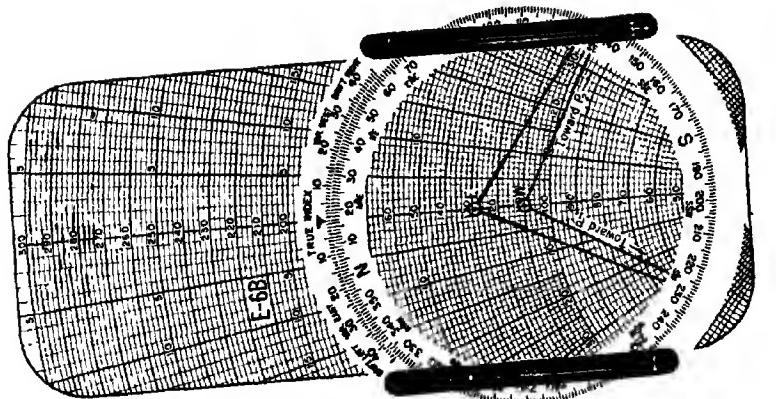
Figure 136.—Double drift on the Mark VII and E-6B.
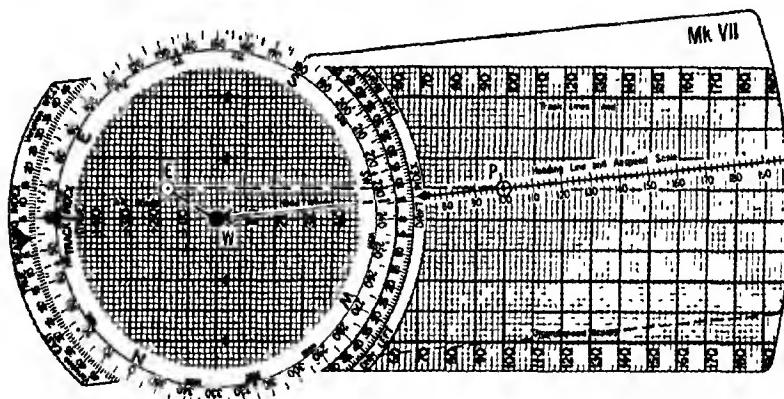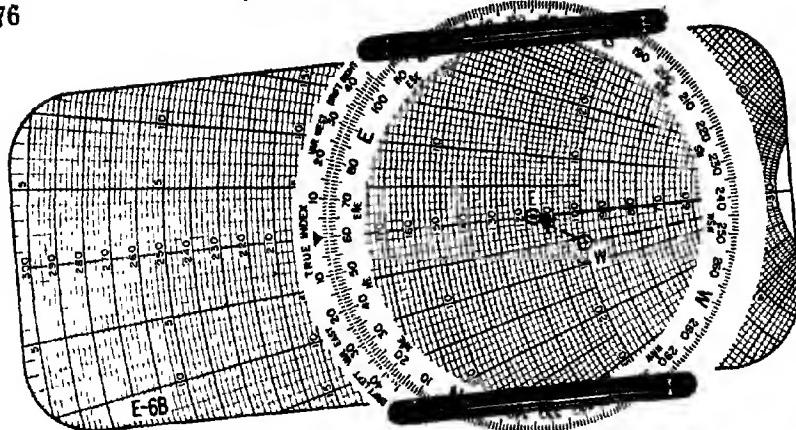
Figure 137.—Radius of action on the Mark VII and E-6B.

The data for the entire problem, using this method, may be taken from the setting for the flight out, and tabulated as follows:

$$TC_o = 060°$$
$$\underline{\quad - 6\ WC}$$
$$TH_o = 054°$$
$$GS_o = 117\ mph$$
$$= AS + 17$$
$$GS_b = AS - 17$$
$$= 83\ mph$$

$$TC_b = 240°$$
$$\underline{\quad + 6\ WC}$$
$$TH_b = 246°$$

Referring to figure 111, it is seen that with this method the GS_b is in error by only 1 mph; solving for radius of action with the slide rule side as already described, the time to turn is still found as 1.24. By mathematics the error involved is one-half minute. Whenever there is
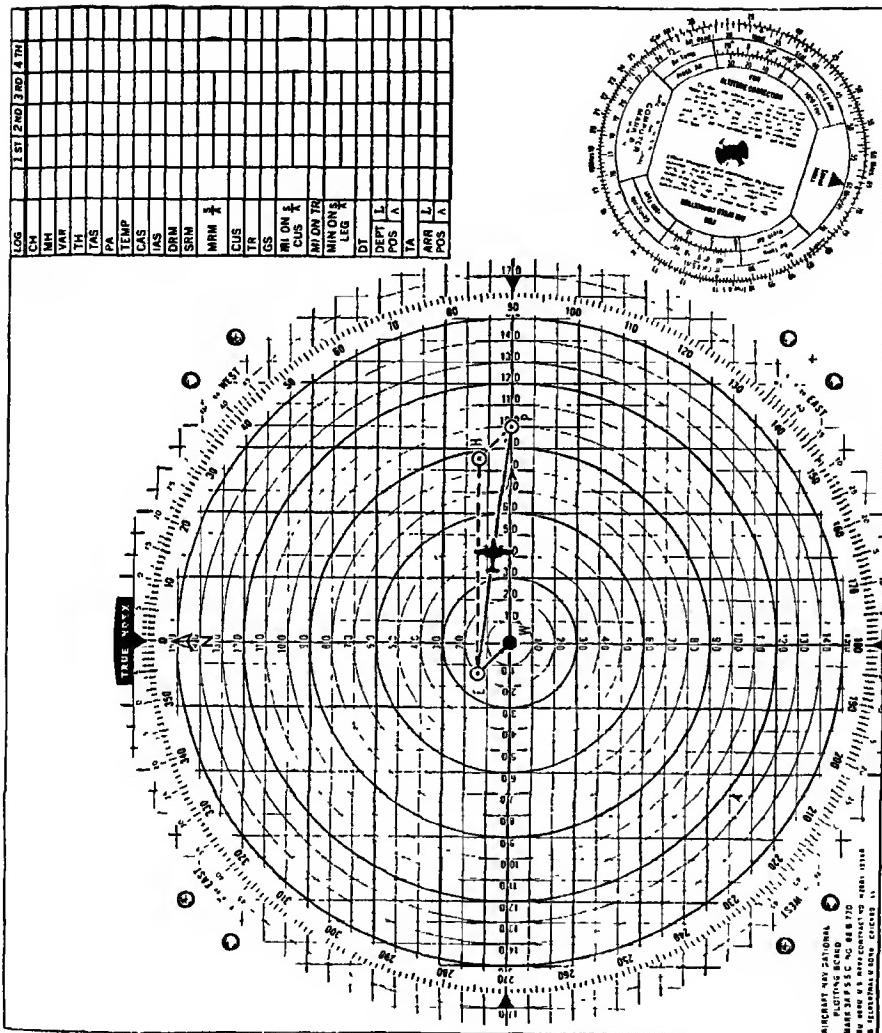
Figure 138.—Simple drift problems on the Mark 3A (problem of fig. 84).

any question, precise results can be obtained only by solving separately for the triangle out and for the triangle back.

ALTERNATE AIRPORT PROBLEM

Figures 114 and 115 show one method of solution for this problem. The method was presented primarily for the clearness with which all parts of the construction can be explained. In practice, the method described in figure 116 provides a more straightforward and rapid solution. Since the latter is essentially the problem of flight from a moving carrier, the solution will be worked out on the Mk. 3A plotting board, which is used chiefly by the Navy. In order to save space, solutions of the previous simpler problems have not been shown on the Mk. 3A; to avoid misunderstanding, several of the simpler problems will be demonstrated on the Mk. 3A before proceeding with the alternate airport problem.

The one rule always to be observed with the Mk. 3A is that W is to be located at the center of the board and E is to be plotted *into* the wind. This is to permit full use to be made of the air speed circles, air speed (WP according to the standard system of lettering) always being measured from the center of the board.

The simple drift problem of figure 84 is illustrated in figure 138. The wind vector is plotted by bringing the "true index" to 315° and laying off the wind velocity *toward* 315° in accordance with the scale of the rectangular grid. The true index is then returned to 0° and WP is drawn representing the true heading and air speed, with EP representing the track and ground speed.

In figure 139 the problem of figure 86 is shown. The wind is plotted as before; then with the true index at 0°, EP is drawn along the grid line parallel to the 090° line from the center (representing the track which it is desired to make good from E) to intersect the air speed circle of 100 mph at P. The true heading and air speed are represented by WP, the true course and ground speed by EP.

Now taking up the alternate airport problem of figure 115 but using the method of 116, the plot is shown in figure 140. The wind vector is plotted as before, laying off E *into* the wind (toward 090°). The true index is then brought to 230° and the line EP is drawn along the grid lines parallel to the 230° setting, to represent the intended track, or true course; WP is drawn to the intersection of EP with the air speed circle for 100 mph. As always WP is the true heading and air speed, EP the true course and ground speed.

The remainder of the solution depends on locating the points S and P_2. The points P, S and P_2 are often referred to as I, II, III, respectively, since the problem as a whole depends on these three points.

Point S is the position of the "carrier" at the end of one hour, or the total distance between E and the alternate airport A divided by the total time available—in short, the position of E at the end of an hour's imagi-
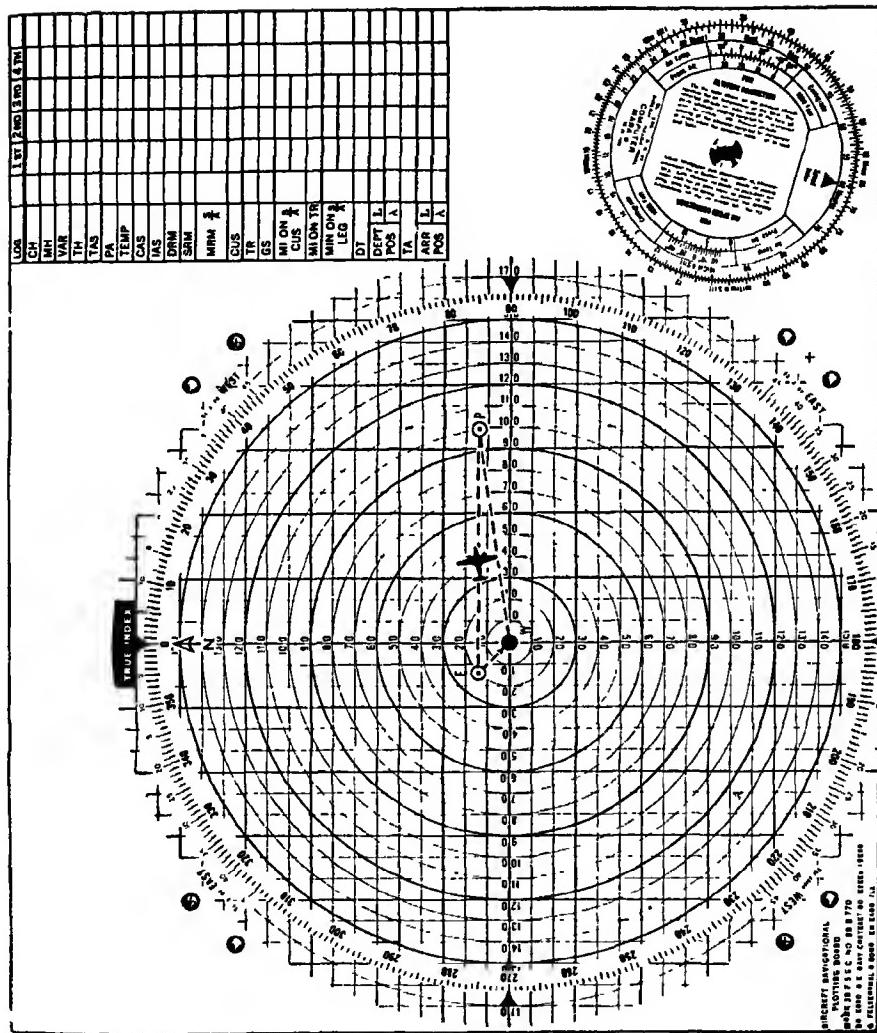
Figure 139.—Allowance for wind on the Mark 3A (problem of fig. 86).

nary motion toward A. Point P_2 is obtained by extending PS until it intersects the true air speed circle.

In order to locate S it is necessary to determine the direction and distance of A from E. In most cases this may be most easily determined from the chart. When this is not the case, some unobstructed portion of the board must be used for a "geographic plot" of the three airports.

In figure 140, E is located at any convenient grid intersection in the upper right part of the board, since the plot in general will be toward the southwest; when locating E, of course, the true index should be at 0°. The geographic plot is an entirely separate drawing and may be at any convenient scale, rather than the scale of the wind triangles. The true index is now brought to 230°, the true course from E to D, and D is located 350 miles distant from E along the grid line (or space) on which E is located. The true index is then returned to 0°, and A is located 140 miles due north of D.

By turning the grid so that E and A both lie along the same grid line, the bearing of A from E may be read at the true index as 252° 30', while the distance is determined by the grid spaces between the two points as 281 miles. While the grid is so oriented, the line ES may be drawn, extending it as far as appears necessary. Since 4 hours of flying time are available, S can now be plotted one-fourth the distance from E to A. The point P_2 is next located by aligning the grid with P and S and drawing a line from P through S to intersect the true air speed circle; WP_2 and EP_2 are the true heading and air speed after turning back, and the true course and ground speed, respectively.

The rate of departure (R/D_o) from the "carrier" (speed of relative movement out, SRM_o) is represented by SP; the rate of return (R/R) after turning (speed of relative movement back, SRM_b) by SP_2. These are scaled from the plot as 62 and 132 miles, respectively. Substituting these values in the radius of action formula, the time to turn is found as 2:43:00—

$$\frac{62 + 132\ (A)}{4:00\ (C)} = \frac{132\ (A)}{t_o\ (C)}$$

The problem can be solved on the Mk. VII, using the compass disk in the same way as the Mk. 3A, as shown in figure 141. First, a wind triangle for the flight out is set up in the usual way, at the normal scale of the computer, in order to determine the true heading and ground speed out as accurately as possible.

Next, if the distance and direction from E to A are not known, they must be determined from a geographic plot worked out in exactly the same way already described for the Mk. 3A. This should be at as large a scale as possible, but will usually have to be at a scale of 10 miles to each grid square. The geographic plot may be located either in an unneeded part of the compass disk, or near the center of the disk; in the latter case, the direction and distance from E to A are written down, and the plot erased
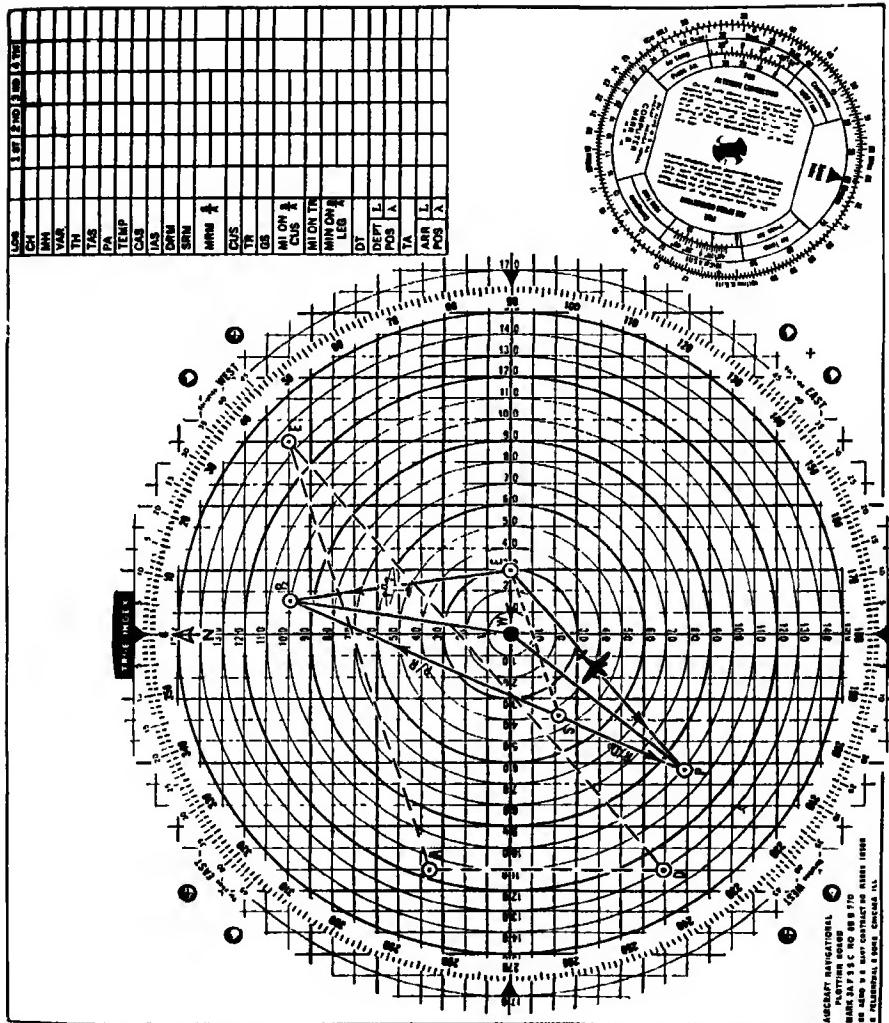
Figure 140.—Alternate airport problem on the Mark 3A (problem of fig. 115).
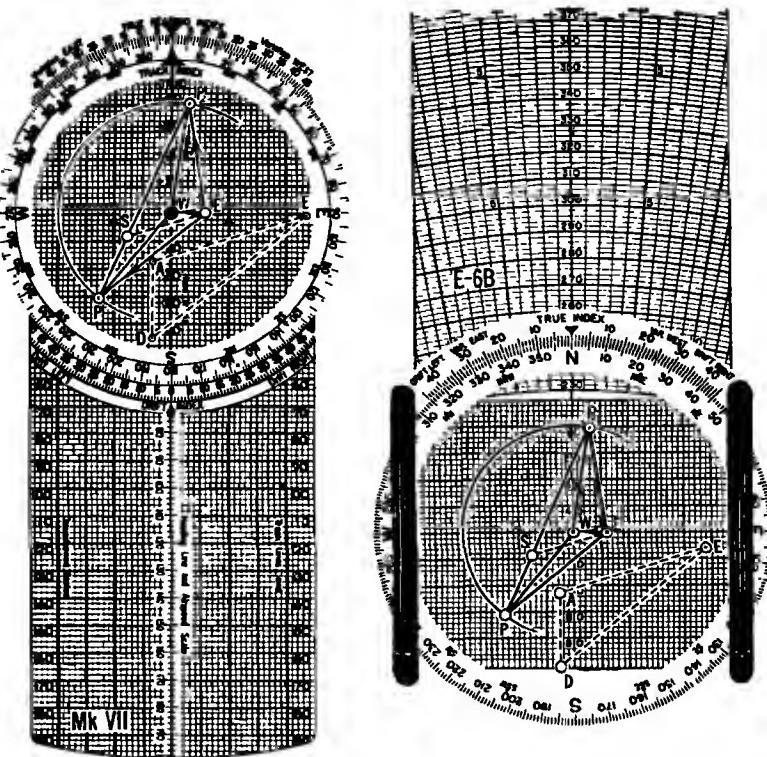
Figure 141.—Alternate airport problem on the Mark VII and E–6B (problem of fig. 115).

Finally, the combined drawing of the triangles for the flight out and the flight back is constructed. As with the Mk. 3A, W is located at the center of the disk, using the largest scale possible (in this case, 5 miles to each grid square). E is plotted into the wind, 30 miles from W. The air speed circle for 100 mph is drawn by holding the pencil point against the compass disk, over the "Head wind scale" and 100 miles from W, and rotating the disk under the pencil point. The true course out, 230°, is then brought to the true heading index, and P is located on the air speed circle along the same vertical grid line as E. Point S is located in the direction EA, 252°, and 70 miles distant from E. Last of all, P_2 is located by aligning P and S horizontally and following the same grid line to its intersection with the penciled air speed circle. With the compass disk so aligned, points P and P_2 should always be equidistant from the vertical center line of the grid (the "track index" line). This can easily be proved by geometry.

As always, WP_2 represents the true heading (009°) and air speed EP_2 the true course (352°) and ground speed (99 mph) after turning. The rate of departure $SP = 62$ mph, and the rate of return $SP_2 = 132$ mph. From these data the time to turn is found from the usual formula.

While the scale of the Mk. VII is rather small for this purpose, fortunately the various parts of the solution tend to compensate for the approximations involved. The time to turn usually differs from the exact

figure by not more than a minute or two, although the true course and heading after turning may be several degrees in error unless the plotting is carefully done.

The problem can be solved in exactly the same way with the E–6B, inserting the rectangular grid under the compass disk after obtaining the true heading and ground speed for the flight out in the usual way.

The use of the geographic plot on the Mk. 3A or the other computers has another practical application. Suppose, in the problem just discussed that, instead of continuing to the maximum distance before turning, after flying for 1:20:00 the pilot was advised by radio that weather had closed in at his destination and he should proceed to the alternate airport.

With the data already on the compass disk, only a few moments are required to determine the true course and distance and the ground speed from his position at the moment to the alternate.

Suppose that the pilot maintains his original heading for 3 minutes to insure time enough for obtaining correct results without hurrying. The elapsed time will then be 1:23:00; at a ground speed of 121 mph this represents 168 miles made good, as quickly determined from the slide rule side. The true course of 230° on the compass disk is again brought to the true heading index and 168 miles laid off from E toward D; this represents the point reached in 1:23:00. The compass disk is then turned until this point and A are aligned with the grid and the true course of 279° to A is read at the true heading index; the remaining distance to A is read from the grid as 142 miles.

Now with the known true course and air speed, and the known wind, the usual large wind triangle is solved, and the true heading is obtained as 283°, ground speed 129 mph; time to make good 142 miles at 129 mph = 1:06:00.

Figure 142 shows the Mk. 3A solution for the problem of figure 116, including the geographic plot. No detailed description of this solution is given, but the student should follow it through on his own computer, for valuable practice. If any difficulty is met, reference to figure 116 or to the problem just explained should point the way to the correct procedure.

INTERCEPTION

Figure 143 shows the solution for the problem of figure 122. As with the alternate airport problem, this consists of two parts: the relative motion triangle and the geographic plot. Since the motion of the ship is westward, and the airplane will be intercepting from a point to the north, the geographic plot is placed in the lower right corner. Base B is located at a convenient grid intersection; the true index is brought to 015°, and the airport A located 125 miles distant. Next, the ship's motion to the time when interception is started (3 hrs. at 30 mph = 90 miles due west) is plotted and labeled T (Time of start of interception); the actual time is usually added also, as shown in figure 119.

With W at the center of the board, the true index is brought to 315° and the wind vector is plotted to E; the true index is then brought to 270°
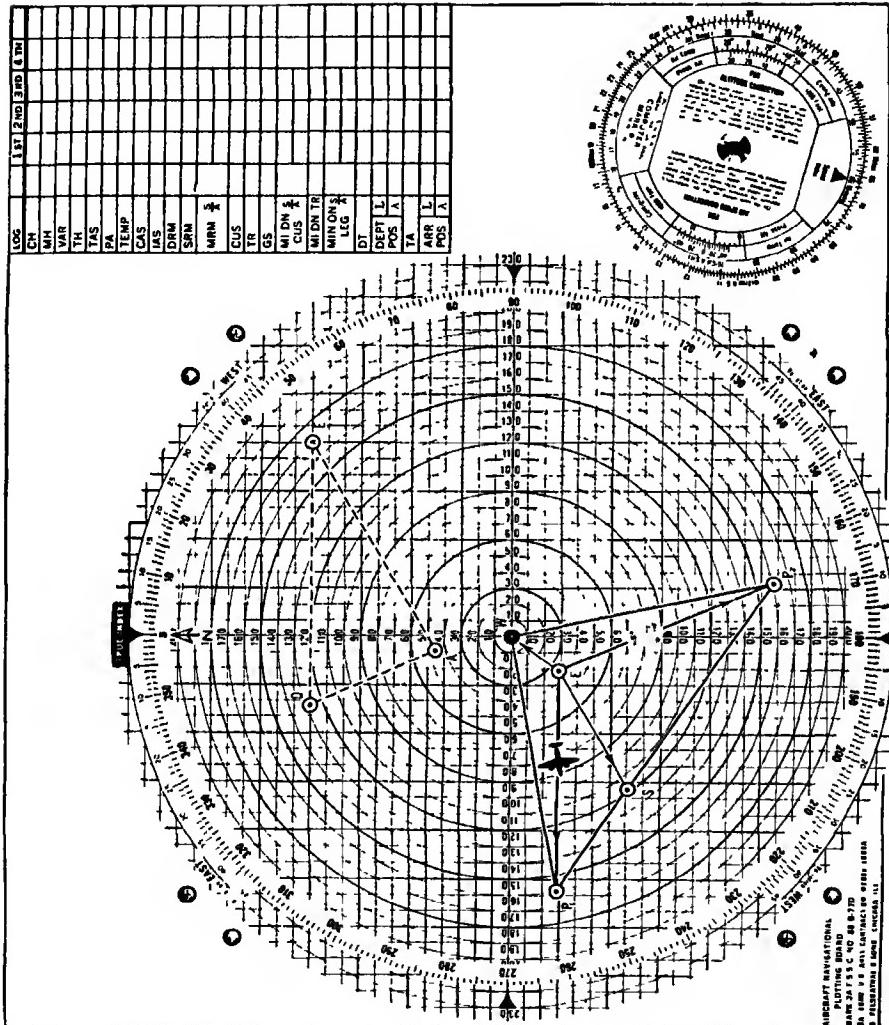
Figure 142.—Alternate airport problem compared with flight from moving carrier, using the Mark 3A (problem of fig. 116).
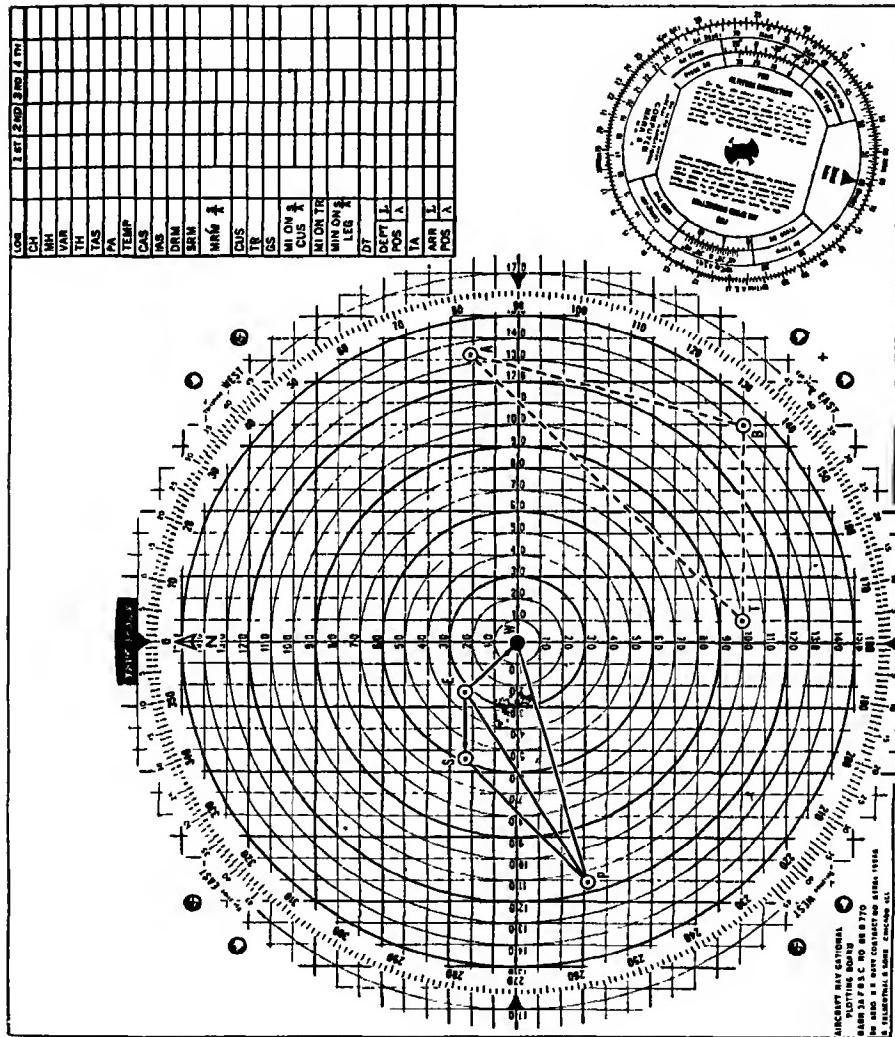
Figure 143.—Interception on the Mark 3A (problem of fig. 122).

and the ship's movement per hour is plotted to S. From S the true bearing of the ship is plotted by aligning A and T of the geographic plot and drawing a line from S parallel to the grid lines (and therefore parallel to AT); the true bearing of 226° may be read at the true index. The intersection of the line drawn from S with the air speed circle for 115 mph locates the point P; EP represents the true course (track) necessary to maintain the required constant bearing, and also the ground speed; WP the true heading necessary to make good that track.

From the geographic plot, the distance to intercept is 172 miles; from the relative movement triangle the rate of interception SP is found as 80 mph. The time for interception, then, is the time required to close the 172 miles at 80 mph, or $172 \div 80 = 2.15$ hrs., or 2:09:00.

Obviously this problem can be adapted to the Mk. VII or the E–6B, just as described under the alternate airport problem, although the smaller scale of these computers will not permit as accurate results.

If the ship to be intercepted changes course, the problem is no more complicated, except that a separate triangle must be solved for each course change. This is illustrated in the following problem, which is worked out for the Mk. 3A in figure 144.

A convoy leaves Base B at 1420, on true course 258° at 22 knots, changing course at 1450 to 240° at 27 knots. At 1510 a pilot leaves Airport A to intercept the convoy, at a true air speed of 105 knots; wind is from 180° at 30 knots. At 1520 word is received by radio that the convoy is again changing course to 258° true at 22 knots. Airport A is 173° and 148 nautical miles from B.

The first step in the solution is the geographic plot, which is placed in a part of the board not required for the problem. Points A and B are located and the track of the ship is plotted from B to the time when interception is started. T_1 marks the position of the ship at time 1450, the time of the first course change, and T_2 marks its position 20 minutes later at 1510, one-third of its hourly speed distant from T_1 on the new course of 240°. This is all the information regarding the ship's motion available when interception is started. The direction of the ship from A at start of interception is determined as 345°, and the distance to the ship is 145 miles.

With W at the center of the board, E is plotted into the wind, and S_1 and S_2 are plotted from E; ES_1 is the ship's movement for 1 hour on the course of 240° being followed at the start of interception, ES_2 is its movement for 1 hour on the changed course after 1520, when the convoy had returned to its original course of 258° and speed of 22 knots. The vector ES_2, of course, and the rest of the second triangle, could not be plotted prior to beginning the flight as the information was not received until 10 minutes after the take-off, at 1520. Points P_1 and P_2 are located by plotting the true bearing of 345°, which is to be constantly maintained throughout the flight, from S_1 and S_2, respectively, to intersect with the true air speed circle of 105 knots. The two relative wind triangles are then completed, the second being shown in figure 144 by broken lines. The data from the two
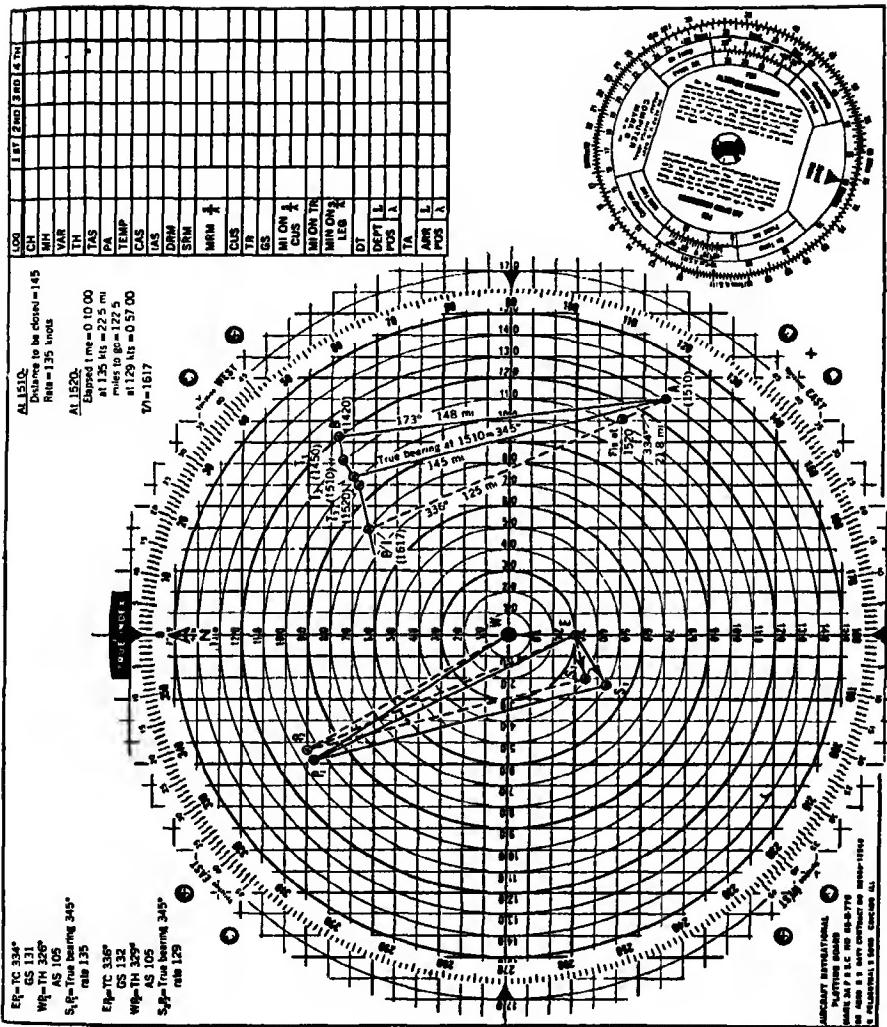
Figure 144.—Intercepting a ship when course and speed are changed, using the Mark 3A.

triangles are tabulated at the upper left of the figure, the use made of the data at the upper right.

At the start of interception the distance between the airplane and the convoy is 145 miles; the rate of approach S_1P_1 is 135 mph. At 1520, when the convoy changed course, the airplane had been in flight for 10 minutes, closing 22.5 miles of the distance between it and the convoy. When notified of the change of course, only three lines had to be drawn and scaled (ES_2, S_2P_2, and WP_2) in order to know the new heading, the new track, and the new rate of approach. From the slide rule side it is quickly determined that the remaining 122.5 miles will be covered at 129 mph in 0:57:00, making the time of interception 1617.

The accuracy of the solution can be checked by setting up on the computer the successive true headings being flown and, with the known air speed and wind data, determining and plotting the track and distances made good.

In the first instance, with true heading 326°, the track is about 334° and the distance made good at the ground speed of 131 mph is 21.8 miles. On the geographic plot this track and distance are drawn from A as shown by the light broken line in figure 144.

In the second instance, with true heading 329°, the track is nearly 336° and the distance made good at the ground speed of 132 mph is 125 miles. Plotting this track and distance from the position already obtained, we arrive at the point of interception (P/I) previously plotted for the ship's movement.

In practice an exact check cannot be expected in this way, since courses and bearings are obtained from the plot only to the nearest degree. In the problem just finished, the actual track differs from the value indicated by nearly half a degree, and the plotted track failed to meet the P/I by a mile or so. With a combination of errors of negligible amount, the position might fail to check by several miles.

TRACKING

This is one of the simplest problems on the Mk. 3A. It is only necessary in each case to bring the true index to the true heading on the compass rose and, using the grid scale, lay off the distance on each leg. The plot may be made continuous (as in fig. 123), without regard for wind effect, applying to the no-wind position at any given time the full effect of the wind up to that time (as in fig. 124), in order to find the current position.

This problem, also, can be performed on the compass disks of the Mk. VII and the E–6B, although the smaller scale makes this hardly practical. Here, again, the better practice is to plot the track directly on the chart.

LATITUDE AND LONGITUDE

Closely related to the problem of "tracking" is the problem of determining the latitude and longitude of the point reached at any given

time. In order to facilitate the solution of such problems, transparent templates are available from the Navy Department, showing an approximate Mercator projection and the principal coastal features of the United States and possessions. Similar templates are available from the same source, showing the Lambert projection but without shore line, making them suitable for use in any longitude. Templates are intended to be inserted between the working surface of the plotting board and the grid disk, still permitting clear visibility of the grid. By reference to the projection of the template it is an easy matter to scale off the latitude and longitude of the point reached at any time.

When the desired templates are not at hand an approximate Mercator projection may be constructed on the plotting board, as follows: Bring the true index to 0° and draw in the parallels of latitude by tracing the horizontal grid lines spaced 60 miles apart. Number these parallels as whole degrees of latitude, with the central parallel numbered to correspond to the latitude near the center of the area of the problem.

Now bring the true index to the number of degrees corresponding to the mid-latitude and, along the diameter of the grid at right angles to the true index line, mark with circle-and-dot the intersections at 60-mile intervals from the center of the board, in each direction. Then return the true index to 0° and through the circled dots draw lines parallel to the vertical lines of the grid. These represent meridians 1° apart on the approximate Mercator projection; number the meridians to correspond to the longitude of the area of operations.

With the completed projection on the board and the true index at 0°, the latitude of any point may be read from the horizontal lines of the grid, which are uniformly spaced 10 minutes of latitude apart. The longitude of the point may be determined by drawing a vertical line from the point which will pass between the circled dots used for drawing the meridians; rotating the true index again to the number of degrees corresponding to the mid-latitude of the projection; and reading (from the diameter of the grid disk at right angles to the true index line) the number of minutes at which the vertical line drawn from the point crosses the diameter.

In practice, the actual projection need not be drawn on the board. It is only necessary to dot and circle the points through which the parallels would be drawn and number them; then to dot and circle the points through which the meridians would be drawn, and number them; and finally to draw the inclined line through the circled points for the meridians. The latitude of any point can be determined from the grid itself, as already described; the longitude can be determined by drawing a short section of a vertical line from the point, crossing the inclined line between the meridian dots, then turning the disk until one of its diameters coincides with the inclined line, and reading the longitude.

In high latitudes, where even an accurate Mercator projection has its difficulties, the use of the approximate Mercator just described is scarcely accurate enough. At latitude 75° errors in direction of more than 5° in an east-west distance of 225 nautical miles are found, with corresponding

errors in position. In such areas an approximate Lambert projection can be drawn on the Mk. 3A, if required.

For example, let it be required to construct a Lambert projection centered at latitude 73° north, longitude 160° west. With the true index at 0° draw the central meridian along the true index line, and label it 160°. Now bring the true index to 73° and along the diameter at right angles to the true index line mark with circle-and-dot the intersection 60 miles from the center, toward the right. Return the true index to 0°, and 0.8 degree beyond (that is, true index at 359°2); the 0°8 is the convergence of any meridian in this projection band with respect to any other meridian a degree distant (see p. 47). With the true index in this position a line through the circled dot parallel to the nearly vertical grid lines will represent the meridian for 159°.

With the true index at 0°, it is noted that the 159th meridian is about 17 miles east of 160°, measured along the diameter perpendicular to the true index line. Since the meridians of the Lambert projection are evenly spaced along any given parallel, the true index is now turned 1°6 west of 0° and the 158th meridian is drawn 17 miles east of the 159th, measured along the same diameter. The true index is successively turned 0°8 farther westward for each additional meridian until all have been drawn.

In order to draw the parallels, return the true index to 0° and along the horizontal lines numbered, 0, 60, 120, etc., draw the section of each parallel between the meridians for 160° and 159°; move the true index 0°8 westward and, from the ends of the lines just drawn, extend the parallels 1° eastward; then move the true index 0°8 farther toward the west and extend all parallels another degree eastward, in each case drawing the lines parallel to the same grid lines.

With the east half of the projection completed the west half is drawn in the same way, remembering that the two halves are symmetrical and that on both halves the meridians converge toward the central meridian, at the top.

With the necessary projection indicated on the Mk. 3A, either by full lines or by circled dots, the airport of origin (or the initial position of the carrier) is plotted by latitude and longitude. This serves as the origin for the geographic plot; any wind triangles or relative movement problems can still be solved at the center of the board, as a separate problem. The procedure is further illustrated by the following example.

A destroyer leaves base B, latitude 38° 42′, longitude 74° 56′ west, at 0925, on a true course of 125°, at 25 knots. At the same time an airplane leaves airport A, latitude 37°53′, longitude 75°36′, on true course 075°, ground speed 120 knots; at 1015 heading is changed to make good a true course of 165°, ground speed 128 knots; at 1039 heading is again changed to 300°, ground speed 117 knots. At 1104 a submarine was sighted below. Find: position of submarine, position of destroyer, and distance and direction of submarine from destroyer.

By rough estimate it is seen that the flight will be in general toward the east, for a little more than 100 miles, corresponding to about 2° of
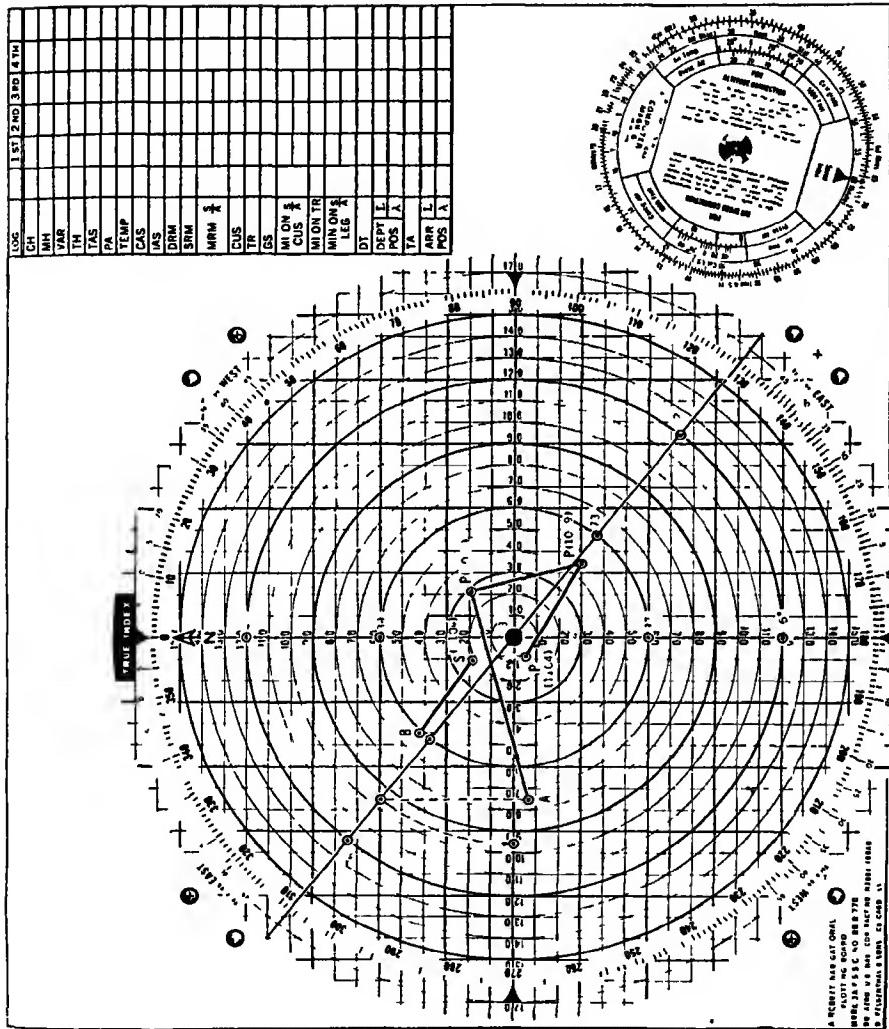
Figure 145.—Latitude and longitude on the Mark 3A.

longitude at this latitude. Consequently the center of the board is taken as latitude 38°, longitude 74°. With true index at 0°, horizontal lines may be drawn at 0, 60, 120, etc., to represent the parallels, or the grid inter-sections at 0, 60, 120, etc., may be circled as in figure 145, allowing the grid lines themselves to serve as the parallels. Next the true index is turned to 38°, and a line is drawn along the cross-diameter, and circled crossmarks are made at 60, 120, etc.; then with the index returned to 0°, vertical lines may be drawn through the circled crossmarks to represent the meridians, or the circled dots themselves may be allowed to represent the positions of the meridians with respect to the vertical grid lines. In either case, the meridians and parallels (or the circled dots representing them) are numbered, as shown in figure 145.

Base *B* is now located, the course of the ship indicated, and the distance made good between 0925 and 1104 at 25 knots = 41 miles is plotted. The position is labeled "S (1104)" and its latitude is determined as 38°19′, longitude 74°13′.

Airport *A* is located and the true course and distance made good between 0925 and 1015 at 120 knots (100 nautical miles on true course 075°) is laid off, and labeled "P (1015)"; then the true course and distance to 1039 (51 miles on true course 165°); and finally the true course and distance to 1104 (49 miles on true course 300°). This position is marked "P (1104)," and the latitude is read as 37°54′, longitude 74°11′.

The direction from the 1104 position of the destroyer to the corresponding position of the airplane (which is the same as that of the submarine), is 176°, and the distance is 25 miles.

From the preceding discussion the way in which this problem can be adapted to the Mk. VII and the E–6B should be obvious. It is quite possible, even on these small-scale computers, to construct a projection covering about 3° of latitude and of longitude at a scale of about 1:3,000,000, which is the scale of the long range navigation charts. In general, however, it seems more practical to plot problems of this nature directly on the chart of the area, rather than to work with small-scale approximations, of limited accuracy, which must still be referred to the chart before the results obtained take on much meaning. When this is done, however, care should be taken to distinguish between the graphic scales printed on the charts (which are in statute miles) and the nautical miles (minutes of latitude) in which many problems of this kind are worked.

RADIO BEARINGS ON A MERCATOR CHART

Since a radio impulse follows a great-circle track, a radio bearing represents the initial direction of the great circle between the positions of the aircraft and the radio station. In order to plot a radio bearing as a straight line on a Mercator chart, the great-circle direction must be converted to a rhumb-line direction. As discussed more fully in Chapter IX, the necessary correction is equal to one-half the convergence between the meridians passing through the aircraft and the radio station.

Mathematical Method.
Corr = ½ diff. of long. x sin mid-lat.
= 5° x 0.866 = 4°.33

Proof of Graphic Method:
AC = ½ diff. long

$$\frac{BC}{AC} = \sin 60°$$

Corr = AC x $\frac{BC}{AC}$ = BC

A = mid-lat. = 60°
AC = ½ diff long. of 10° = 5°
BC = Corr : Scales 4°.33
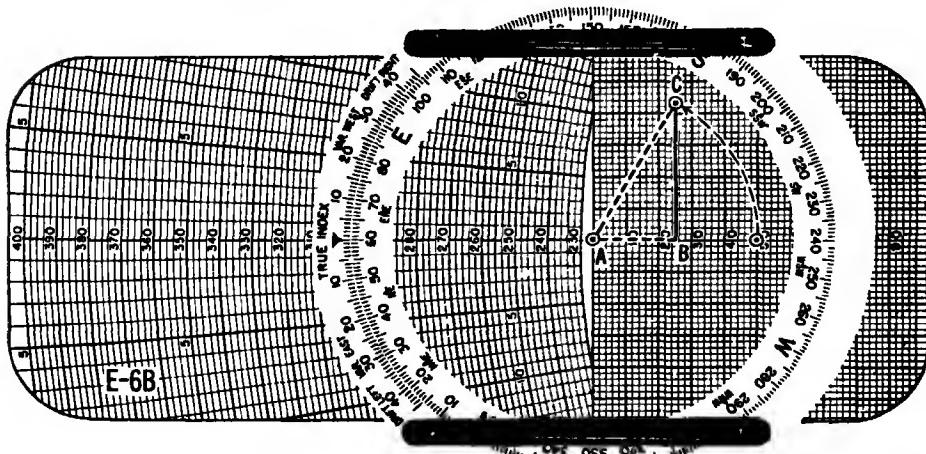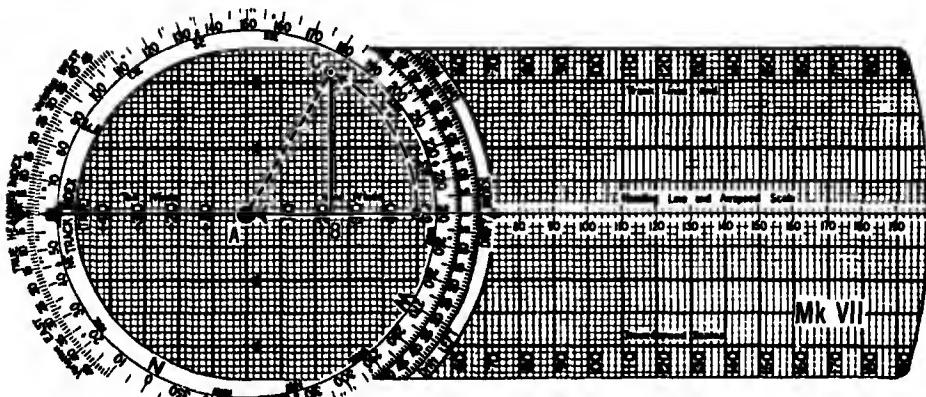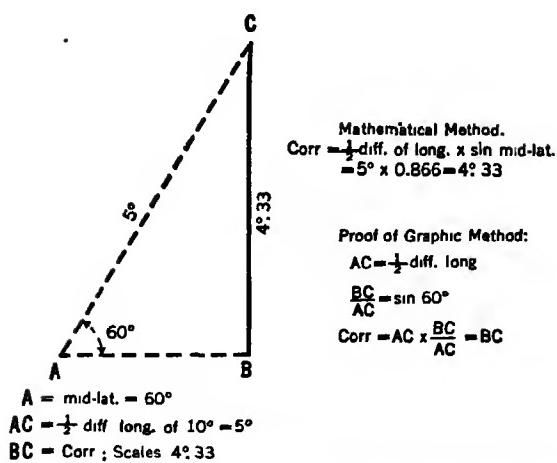
Figure 146.—Mercator correction to radio bearings.

"Convergence" as used here refers to the convergence of meridians on the earth. It has no reference to the convergence of meridians of a particular Lambert projection (see p. 47), although the Lambert convergence closely approximates that of the earth. The correction for convergence discussed here is unnecessary when the properties of the Lambert projection are used to best advantage.

The correction for convergence may be determined with sufficient accuracy as one-half the difference of longitude multiplied by the sine of the mean latitude between the two positions. It may be obtained graphically or by mathematics, as in the upper part of figure 146. It may also be determined easily with computers such as the Mark VII and E–6B, as shown in the lower part of the same figure.

With 0° at the true index, one-half the difference of longitude is laid off below the center of the disk. When the difference of longitude does not exceed 10°, a scale of 1° for each 10 miles of the grid can be adopted; that is, the zeros may be disregarded, and 10, 20, etc., may be read as 1, 2, 3, 4, and 5 degrees. In this case, a circled dot is placed at 5 (equal to one-half the difference of longitude). The compass disk is then rotated until the mid-latitude (60° in this problem) is brought to the true index, when the correction is read as 4°33, the distance of the dot from the center grid line.

From the foregoing, the determination of this correction on the Mk. 3A will be obvious.

QUESTIONS

1. What two "indexes" or reference points are printed on the slide rule side of most computers? Describe the general purpose of each such index.

2. Name a third index often added to the slide rule side, and state its purpose.

3. What is meant by the *A*, *B*, and *C* scales of an air navigation computer?

4. Why is temperature a factor in the computer setting to determine the true air speed?

5. If the Fahrenheit temperature were reported and your computer contained only the centigrade scale, how would you convert to centigrade?

6. State the formula for radius of action in its most convenient form for solution by computer.

7. When using the E–6B when should the wind vector be laid off *with* the wind, when *into* the wind?

8. In determining the true heading to make good the intended track, using the E–6B, should the air speed curve be brought under the center of the compass disk, or under the dot at the end of the wind vector?

9. Can all four computers discussed in this chapter be used for the determination of wind by double drift?

10. Describe the approximate method for solving simple radius of action problems at one setting of the computer.

11. How may the alternate airport problem be compared to flight from a moving aircraft carrier?

12. Why is W always placed at the center of the Mk. 3A plotting board?

13. What is the best way of determining distance and direction between two points?

14. Is it more, or less, desirable to plot track on a copy of the chart than on the grid of the plotting board? Why?

15. Why must a radio bearing be corrected before it can be plotted on a Mercator chart?

PROBLEMS

1. Multiply the following numbers, and check your results by arithmetic:

87×24	39×26	228×28
8.7×2.4	92×3.9	22.8×22.8
240×33	77×6.3	125×16.2
27×27	7.7×36	32×23
19×27	43×15	4.7×38

2. Perform the division indicated, and check your results:

$273 \div 91$	$242 \div 12$	$228 \div 28$
$27.3 \div 90$	$408 \div 27$	$125 \div 15$
$3.9 \div 13$	$9.6 \div 4.8$	$88 \div 24$
$275 \div 5.5$	$64.5 \div 43$	$96 \div 16$
$318 \div 10.6$	$359 \div 92$	$230 \div 4.8$

3. Solve the following problems in percentage:

23% of 180	93% of 125
30% of 165	125% of 93
80% of 142	12.5% of 93
76% of 135	39% of 156
34% of 173	113% of 169

4. Obtain 86% of the following numbers:

28, 34, 125, 165, 180, 16, 115, 52, 365, 144

5. Indicated air speed on climb is 120 mph to cruising altitude of 8,000 feet. Elevation of airport is 1,000 feet. What is the true air speed? (Hint: without knowledge of temperature, the approximate correction is 9%; see p. 130; 109% of 120 mph =   ?)

6. Indicated air speed on descent is 90 mph from cruising altitude of 4,000 feet to airport at 600 feet. What is the true air speed?

7. Solve the following problems in proportion:

$$\frac{24}{36} = \frac{30}{x}, \qquad \frac{x}{125} = \frac{160}{168}, \qquad \frac{18}{22} = \frac{86}{x},$$

$$\frac{36}{24} = \frac{x}{120}, \qquad \frac{210}{x} = \frac{168}{160}, \qquad \frac{82}{95} = \frac{x}{139}.$$

8. In solving a simple radius of action problem, the ground speed out was determined as 92 mph, ground speed back as 123 mph, total time available 3:30:00. Find the time to turn and the distance to the point of turning.

9. In a flight from a moving carrier the rate of departure relative to the carrier was 68 mph, the rate of return 108 mph; total time available 3:00:00. Find the time to turn and the farthest distance from the carrier.

10. In the blanks below, fill in the equivalent centigrade or Fahrenheit temperatures:

Centigrade·	32		100		−10		20		−40	
Fahrenheit:		32		100		−10		20		−3

11. In the blanks below, fill in the equivalent number of nautical miles, statute miles, or kilometers. If your computer does not have the special indexes, or arrows, for these conversions, remember that 1 naut. mi. = 1.15 st. mi. = 1.85 km.; 1 st. mi. = 0.87 naut. mi. = 1.6 km.

Nautical miles	28		115			87		
Statute miles		28		185			225	180
Kilometers.			28		160			326

12. While flying at an indicated altitude of 5,600 feet a temperature of — 4° C. was observed; pressure altitude was 5,000 feet; what was the correct altitude?

13. If, in the above problem, it was known that the temperature at an airport in the same vicinity was +10° C., and the elevation of the airport was 800 feet, what corrected altitude should you have obtained?

14. With a calibrated air speed of 110 mph under the conditions of problem 12, what was the true air speed? With a temperature of 0° C. at 5,000 feet, what would have been the true air speed?

15. A landmark 18 miles out is passed after 11 minutes of flight. What is the ground speed?

16. At a ground speed of 135 mph, how many minutes will be required to make good 10 miles? 25? 63? 92? 108 miles? How many miles in 10 minutes? 30? 45 minutes?

17. A 2-mile speed course is flown in 53 seconds. What is the ground speed? What ground speed if flown in 38 seconds? (Hint: use the 36-index.)

18. An airport is 2.2 miles from a radio range station. At a ground speed of 100 mph, how long will it require to break through over the airport?

19. A given airplane uses 17 gallons of gasoline per hour. How many gallons are required for 2 hrs. 45 min.? At 22 gallons per hour, how many for 3 hrs. 25 min.?

20. With 125 gallons of fuel and a consumption of 23 gallons per hour, how long may an airplane be flown (disregarding any required reserve)?

21. A fuel consumption of 77 gallons in 2 hrs. 12 min. was noted. What is the fuel consumption per hour?

22. With 150 gallons of fuel and an hourly consumption of 22 gallons, how many hours of flying time are available, allowing a reserve of 25%? allowing a reserve of 45 minutes?

23. True course is 240°, true air speed 135 mph; wind from 160° at 24 mph. Find the true heading.

24. True heading is 240°, true air speed 135 mph; wind from 160° at 24 mph. Find the drift angle and track.

25. Compass heading is 135°, true air speed 140 mph, variation 10° E., deviation as in figure 54; wind 270° at 28 mph. Find the drift angle and track.

26. On a true heading of 135° a drift angle of 7° L is observed; on true heading 225° drift is 3° L; true air speed 120 mph. What is the wind direction and velocity?

27. On a true heading of 280° a drift angle of 3° R is observed, and on true heading 190° drift is 6° L; true air speed 135 mph. What is the wind direction and velocity?

28. An airplane is being flown on a true heading of 300° at a true air speed of 105 mph; the track is determined from charted landmarks as 292°, ground speed 97 mph. What is the wind direction and velocity?

29. A pilot is to scout as far as possible on true course 65° and return to the same base. True air speed is 135 knots; wind is 180° at 25 knots; fuel is available for 3 hours 30 minutes. How far from base (in nautical miles) can he fly?

30. It is desired to construct a time scale showing 10-minute intervals on a sectional chart, for a true air speed of 160 mph. Considering the scale as 8 miles to the inch, how long (in inches) should each division of the scale be (that is, the distance covered in 10 minutes, reduced to the scale of the chart) ?

31. The distance and direction from A to B are 320 miles, true course 320°, true air speed 140 mph; wind is 170° at 32 mph. How long will the flight require?

32. Base B is 400 miles distant from E, on true course 025°. Alternate airport A is 335 miles from E on true course 080°. Wind is from 070° at 30 mph; 5 hours of flying time are available, at 120 mph. If the flight begins at 1000, what will be the latest time to turn, the distance from E to point of turning, true heading and ground speed after turning?

33. At start of flight a true heading of 215° is flown, in order to make good a true course of 220°; true air speed 110 mph, distance to go 325 miles. After flying for 01:07:00, a fix is established 16 miles to the left of the intended true course and 136 miles from the starting point. Find wind direction and velocity, and true heading and ground speed from the fix to destination.

34. The true course from A to B is 354°, distance 345 nautical miles; wind is from 300° at 35 knots. A ship leaves B at 1130 on true course of

210° at 28 knots; an airplane leaves A at 1230, true air speed 140 knots, to intercept. Find the time of interception, and the true heading to intercept.

35. A seaplane leaves A at 1420 on compass heading 200°, true air speed 140 knots; at 1500 compass heading is changed to 310°. At 1520 a life raft is sighted below. Wind is from 180° at 20 knots; variation 5° E., deviation as in figure 54. Find distance and direction of raft from A. If latitude of A is 30° N., and longitude is 85° W., find latitude and longitude of raft.

36. Determine (to the nearest half-degree) the correction to be applied to the following radio bearings in order that they may be plotted on a Mercator chart:

Longitude of station	Approximate longitude of aircraft	Mean latitude	Mercator correction
4° 00′ W.	5° 00′ E.	50° N.	
81° 00′ W.	90° 30′ W.	30° N.	
121° 15′ W.	114° 45′ W.	40° N.	
172° 35′ W.	177° 25′ E.	15° S.	
166° 00′ W.	171° 00′ E.	64° N.	

Chapter IX.—RADIO NAVIGATION

THE IMPORTANCE OF AERONAUTICAL RADIO

In many respects, radio navigation offers the simplest and easiest methods of position-finding in flight. Radio aids to navigation are available which keep a pilot on course and warn him of any departure from the radio path; which point out his destination and keep him informed of the weather ahead; provide him with maps and printed communications while in flight; tell him how high he is above the ground; bring him landing instructions from the traffic control towers of busy airports; which even enable him to "see" through fog or haze, and guide him down to safe landings when he cannot see the ground.

The improved equipment and methods now available to the armed forces cannot be discussed in detail during the war, but it is possible to say that radio will be of even wider usefulness and importance after the war than at the present time. One interesting prediction [5] indicates something of the possibilities:

"Air traffic of the future will be guided by chains of ultra-short-wave radio beacons, as air traffic of past years was guided by chains of light beacons. They will cross the continent like highways, enabling the aviator to fly above the clouds and yet see his way in three dimensions by radio vision, as unmistakably as if he were looking at rows of street lights on a clear night."

One important advantage of radio navigation is that it continues to function in blind flying, when other methods fail or become very uncertain. Even the light-plane owner, with no more equipment than an inexpensive portable receiver, may enjoy radio range navigation; with the same equipment he may add to his safety by receiving the latest weather reports while in flight, and landing instructions from the control tower when he reaches his journey's end. Already there are a number of airports where aircraft not equipped with radio are forbidden.

Within the limits of one brief chapter it is impossible to treat in detail all the equipment that is available or to discuss the special methods possible with the various forms, and the merits and disadvantages of each. Rather, it is the aim here to present the general principles involved and to outline the methods of converting the information received into bearings and positions which may be plotted on a suitable chart. An important consideration in this connection is that the underlying principles do not

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[5] From a speech by Dr Ernst F. W. Alexanderson, of the General Electric Company, as reported in the Bulletin of the American Meteorological Society, October 1943.

Figure 147.—The radio range system of the civil airways (1944).

change, although it sometimes seems impossible to keep a text up to date with the present rapid development of radio apparatus.

For the United States, a chart on the Lambert projection is ideal for all methods of radio navigation, since its meridians converge so nearly in conformity with the meridians of the earth that no corrections nor computations of any sort are required. A radio bearing may be plotted directly and correctly on the chart. Within any of the Lambert and stereographic projection bands provided for aeronautical charts of the world (see fig. 32), the same advantages are to be found. For an area centered near the junction between bands, special charts, based on the standard parallels best suited to the area, will provide the same excellent properties.

THE RADIO RANGE SYSTEM

Of the various methods of radio navigation, perhaps the simplest and best known is provided by the radio range system of the Civil Aeronautics Administration, illustrated in figure 147.

Each radio range station marks four courses, or equisignal zones, which are normally 90° apart, although this spacing is often varied in order that the courses may coincide with the established airways. For example (see fig. 148), the northeasterly course of the Jacksonville radio range station is directed along the airway to Savannah; the southeasterly course along the airway to Miami. The westerly course is directed along the airway to Tallahassee, while the easterly course is directed out to sea. The four courses from each station are obtained as follows:
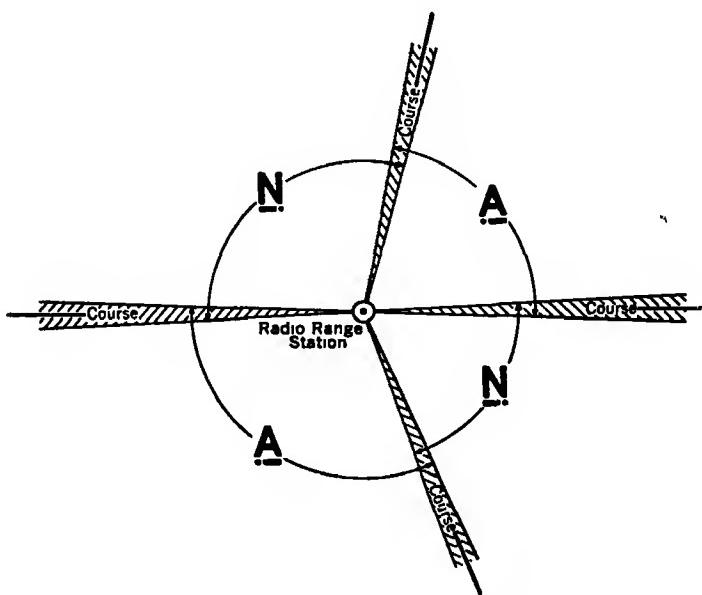
Figure 148 —Jacksonville radio range station.

Into two diagonally opposite quadrants (fig. 148) the letter N (_ .) is transmitted in Morse code, and into the remaining pair of quadrants the

letter A (. _) is transmitted. Each quadrant slightly overlaps the neighboring quadrants, and in the narrow wedge formed by the overlap the two signals are heard with equal intensity, the dots and dashes of the two signals interlocking to produce a continuous signal, or monotone. Thus, a pilot will hear the continuous dash while he is on course; if he deviates to one side of the course he will hear the dot-dash (A) signal, and if he deviates to the other side he will hear the dash-dot (N) signal. The on-course (equisignal) zone is commonly referred to as the "beam." While this is not technically exact, since it is not a beam that is broadcast, it has become so firmly established in popular usage that it will frequently be referred to as "the beam" in this text.

On the aeronautical charts of the Coast and Geodetic Survey the radio range system is usually shown in a pink tint, and the A and N quadrants of each station are indicated by red letters near the ends of the beams; see plates III and IV. For some special purposes, a solid line is printed along the edge of each beam adjacent to the N quadrants, and the letters are omitted. By reference to the chart, pilots may know from the signals received whether they are on course, or to the right or left of the course.

The beam is about 3° in width, depending largely upon the orientation of the courses, the receiving equipment used, and the technique of the observer. Maximum sharpness of the beam is obtained with the receiving set tuned to the minimum practical volume.

As an aid to orientation, a uniform procedure is followed in the designation of quadrants. The letter N is always assigned to the quadrant through which the true north line from the station passes; or if the center of a beam coincides with true north, the letter N is assigned to the adjacent quadrant on the west. In Canada the letter N is assigned to the northwest quadrant, which is the quadrant through which the true bearing of 315° from the station passes.

The range signals are interrupted about twice each minute for the transmission of the identifying signal of the station, which consists of two letters in continental code. This signal is always transmitted first in the N pair of quadrants, then in the A quadrants. If a pilot is near the bisector of an N quadrant, he will hear a series of dash-dot (N) signals, followed by the identifying signal, but will not hear the dot-dash (A) signals, nor the identifying signal which is transmitted into the A quadrants.

If he is on course, he will hear a dash, or monotone about 30 seconds long (the A and N signals interlocked), followed by the identifying signals, which are transmitted first into the N quadrants and then into the A quadrants. As long as a pilot remains on the beam, the identifying signals from both the A and the N quadrants will be heard with equal intensity; when following the beam, therefore, some pilots fly so as to keep these two signals of equal strength instead of trying to maintain the on-course monotone. If a departure from the beam occurs, one identifying signal becomes noticeably weaker than the other; if the first of the two signals received is the weaker, the pilot knows he is in an A quadrant; if the second signal is

weaker, he is in an N quadrant. In either case, of course, he knows his position with reference to the beam. When off course, experienced pilots are able to estimate approximately the angular departure from the beam by means of the relative strength of the two identifying signals received.

Under good receiving conditions the first method (flying so as to maintain the on-course monotone) is more precise; under unfavorable atmospheric conditions the latter method is generally preferred.

At most of the range stations now in operation provision is made for simultaneous broadcast of voice and range signals. By means of filters, pilots may listen to the range signals, the broadcast, or both. All stations equipped for simultaneous broadcast of voice and range signals are also equipped for transmitting an "attention signal" to warn pilots who may be listening only to the range that a voice broadcast is about to be made. This signal consists of a series of dots transmitted for a period of one second (10 to 12 dots). After ending the attention signal, a 5-second delay is observed before beginning the voice broadcast.

At the older stations, a number of which are still in service, the range signals are interrupted at scheduled intervals for brief weather reports of interest to those flying the airway on which the station is located. In order to provide continuous range operation in emergencies, weather broadcasts may be omitted on request.

The radio range stations are usually located near a terminal airport or an intermediate landing field, and, whenever possible, they are so situated that one of the four beams lies along the principal runway or landing area of the airport, thus facilitating radio approach landings under conditions of low visibility.

Airway radio range stations are either full power or medium power, depending on the alignment and distance along the airway to be served. In addition, stations exactly similar to the range stations already described, except that they are of quite limited power and range, are located at or near a number of important terminal airports. They are always so placed as to localize the landing area very definitely, and provide a positive control for landings in bad weather. The range courses from these airport radio range stations are also shown on the aeronautical charts by a pink tint, but the bearings are often omitted because of congestion in the vicinity of major airports. Pilots desiring complete data should obtain them from Flight Information Bulletin No. 3, "Air Navigation Radio Aids," issued by the Civil Aeronautics Administration.

From the foregoing it is evident that the use of the radio range system is basically simple, and should present little difficulty.

Due to the effect of wind, as well as irregularities in maintaining the required heading, it is seldom possible to hold steadily to the track marked out by the beam. Instead, if the pilot is slightly to the right of the beam he heads a few degrees to the left until the on-course signals are heard, then a few degrees to the right until the off-course signals again predominate, etc. In this way he "weaves" along the right-hand edge of the equisignal zone, making frequent checks of the charted bearing of the

beam by means of his compass. There are several other factors, also, which may prove confusing unless the principles involved are understood.

REVERSAL OF SIGNALS

As an airplane passes over a radio range station there is an apparent reversal of the directions of the A and N quadrants. For example, an airplane approaching the radio station of figure 148 from the north will have the A quadrant on its left, the N quadrant on its right; but as soon as it has passed the station the N quadrant will be to the left and the A quadrant to the right.

THE CONE OF SILENCE

Directly above the antennas or towers of the radio range station there is a cone of silence, a limited area shaped like an inverted cone, in which all signals fade out. Just before entering the cone of silence the volume of the signals increases rapidly; as the airplane enters the cone, the signals fade out abruptly for a few seconds, the length of time depending on the speed of the airplane and the diameter of the cone at the level of flight. When the airplane first leaves the cone, the signals surge back with great volume before they begin to fade as the distance from the station increases. If the airplane passes over the station a bit to one side of the cone, and the receiver is not kept to minimum volume, the signals do not entirely fade out.

Sometimes there is a momentary fading of signals, or a false cone of silence, at other points along the airway, but this can be distinguished from the true cone of silence by the nonreversal of signals, and by the absence of the surge of volume at the edges of the cone, which should have taken place in passing over the station. In order to avoid any uncertainty from this cause, ranges are equipped with "Z" marker beacons, which emit a distinctive, high frequency radio signal in the cone of silence. This signal may be received aurally, in the pilot's earphones; or visually, as a light on the instrument panel. Since it is of very high frequency, a separate receiver is required.

MULTIPLE COURSES

Multiple courses exist at some locations—particularly in mountainous country. That is, the equisignal zone, which is normally about 3° in width, may be broken up into a number of narrow on-course bands with a total spread of 10° or 15°, or even more. Between these narrow on-course bands the proper quadrant signal is usually heard, although an A signal is sometimes found in an N quadrant, and vice versa. Figure 149 shows the conditions on the Salt Lake City radio range courses at distances of about 12 and 28 miles from the station.

From figure 149 it may be seen that in most cases a multiple course has the same signal on both sides of the course; also, a multiple course can often be recognized by its narrow width in comparison with a true range course. Pilots can lessen the danger of following one of these false courses away from the established airway by checking the magnetic course being

made good (the compass heading plus or minus deviation and wind effect) against the magnetic direction of the beam printed in the chart. This item is of less importance when flying toward the station, since in most cases even a false range course could be satisfactorily used for homing. In some cases, however, the multiple courses are discontinuous, appearing and dis-
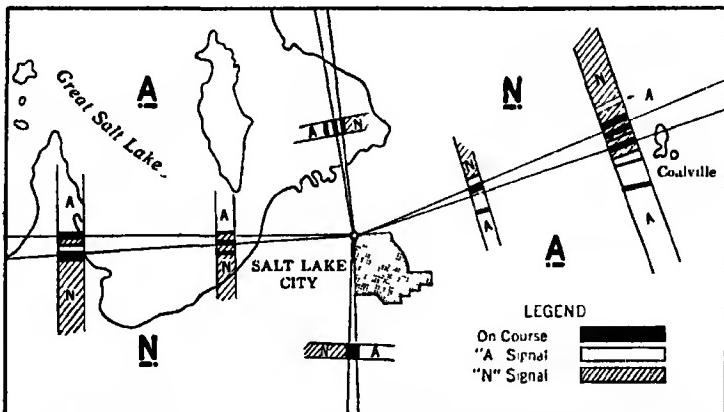
Figure 149.—Salt Lake City radio range station, showing multiple courses

appearing. When a multiple course is used for homing it should be remembered that it may lead over terrain that is dangerous because of high mountain peaks.

BENT COURSES

A related difficulty is found in bent courses. As a rule, the bend is relatively small, and is of little importance since it bends away from and around the obstruction that causes it; however, in mountainous country bends of as much as 45° have been noted. Several such bends may occur in a short distance, and to attempt to follow them without a thorough knowledge of their relation to the terrain, previously gained under conditions of good visibility, might prove impossible. If the airplane continues in straight flight under these conditions, the range courses seem to be swinging from side to side.

NIGHT EFFECT

Beams from range stations using the old loop antenna do swing at night—often to such an extent that they are not usable at distances more than 25 miles from the station. This phenomenon is known as night effect, and has been largely eliminated in more recent installations by using four vertical radiators instead of two crossed loop antennas. At many of the more important ranges a monitoring device automatically transmits a Morse X three times in succession whenever the beam swings out of its intended alignment, providing pilots with a warning of the condition.

SUMMARY

In view of the difficulties mentioned, when flying blind (on instruments) it is important to maintain an altitude well above any nearby peaks

or obstructions—and in interpreting the word "nearby" a generous allowance should be made for any possible uncertainty as to the position of the airplane.

Mention of these weaknesses should not destroy confidence in the radio range system, which as a whole is very dependable, and one of the most effective aids yet developed. They are presented here in order that pilots may be ever on the alert, taking nothing for granted when the safety of life and property is at stake.

Some of these difficulties may be greatly reduced as the result of development work by the Civil Aeronautics Administration. For example, the use of very high frequencies is expected to afford definitely improved performance, including almost complete freedom from static and from orientation problems. Considerable work has been done on an omnidirectional radiobeacon, which is intended to give the equivalent of a range course from any direction toward the transmitter.

THE RADIO RANGE AND DEAD RECKONING

For most effective use, the radio range system should be regarded as an aid to dead reckoning. With any form of radio navigation there is always the possibility of mechanical failure, either in transmission or
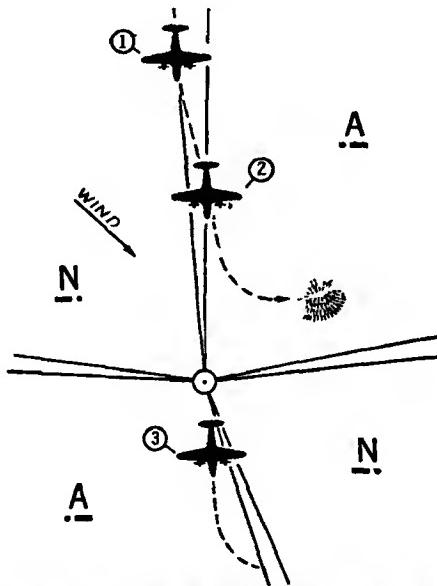
Figure 150.—The danger of neglecting drift in radio range navigation.

reception; in such cases, the pilot who has neglected other methods of navigation may find himself hopelessly lost and without the information necessary for safely completing the flight.

One of the greatest advantages of the radio range system is that pilots need not be directly concerned with corrections for drift. As long as the airplane is kept along the right side of the beam (with reasonable precaution against multiple courses), they can be certain of the track made

good over the ground. This does not mean, however, that drift may be safely neglected; in order to keep the airplane along the edge of the range course it may be necessary to head the airplane into the wind at an appreciable angle. It is important that this angle be observed, and that every possible check should be made of current wind conditions and the proper allowance for wind.

Figure 150 illustrates what actually happened in one case, through failure to make proper allowance for wind. A pilot was flying south, along the right side of the beam, at position 1. Due to a pronounced change in wind direction which had not yet been detected, no allowance was made for the northwest wind. Under the action of this wind the aircraft drifted into the northeasterly *A* quadrant, as shown at 2. The pilot supposed he had crossed the westerly beam, and was in the southwesterly *A* quadrant, at 3. He therefore turned toward the east, with the idea of getting on the southerly beam, but struck the side of a mountain, near 2, as indicated.

THE PROBLEM OF ORIENTATION

Ordinarily, the most difficult problem that may arise is that of quadrant identification and of finding a beam as quickly as possible from an unknown position. This procedure is known as "orientation." For the solution of this problem an accurate aeronautical chart is indispensable; only from this source can the pilot learn the identifying signals of the stations in his vicinity, the relative positions of the four radio range courses from each station, and the magnetic directions of the beams. Here, again, the fact should be emphasized that a chart, once sold, can be corrected only by the user. Before beginning any flight in which the use of radio may become necessary, the charted data should be checked against the latest edition of AIR NAVIGATION RADIO AIDS and subsequent issues of the WEEKLY NOTICE TO AIRMEN, and any changes should be noted on the chart.

In describing the various methods of orientation frequent reference must be made to procedure turns, the "right-hand edge" of a beam, the average bisector, and beam bracketing. These terms will, therefore, first be explained.

Standard procedure turn.—This is a turn made at the standard rate of 360° in 2 minutes (3° a second) by reference to the turn-and-bank indicator; see page 68. If it is desired to reverse the direction of flight along a beam, the airplane should be turned 45° to the right from the heading that kept the airplane along the right-hand edge. This heading should be maintained for about 1 minute; then a 180° turn should be made to the left, and this heading maintained until the far edge of the beam is reached, and the right-hand edge is bracketed.

After the direction of flight along a beam has been reversed any allowance for drift must also be reversed. For example, when approaching the station of figure 151 along beam 4 a magnetic heading of 110° was required to maintain the right-hand edge; that is, an allowance of 6° for

wind has been added; for flight in the opposite direction 6° should be subtracted, and a magnetic heading of 278° should maintain the right-hand edge.

The right-hand edge of a beam.—This phrase refers to the zone where the on-course monotone is continually audible and the signal to the right can also be faintly heard—so faintly that only every fourth or fifth signal can be distinguished.

The average bisector.—When the course-pattern of a station is not symmetrical it is important to use the *average* bisector of the two possible quadrants; admittedly, this is less desirable than using the bisector of the quadrant in which the pilot is located, but it is much more desirable than using the bisector of the *wrong* quadrant. Once the quadrant has been definitely identified, the bisector of the quadrant so determined should be used rather than the average bisector.
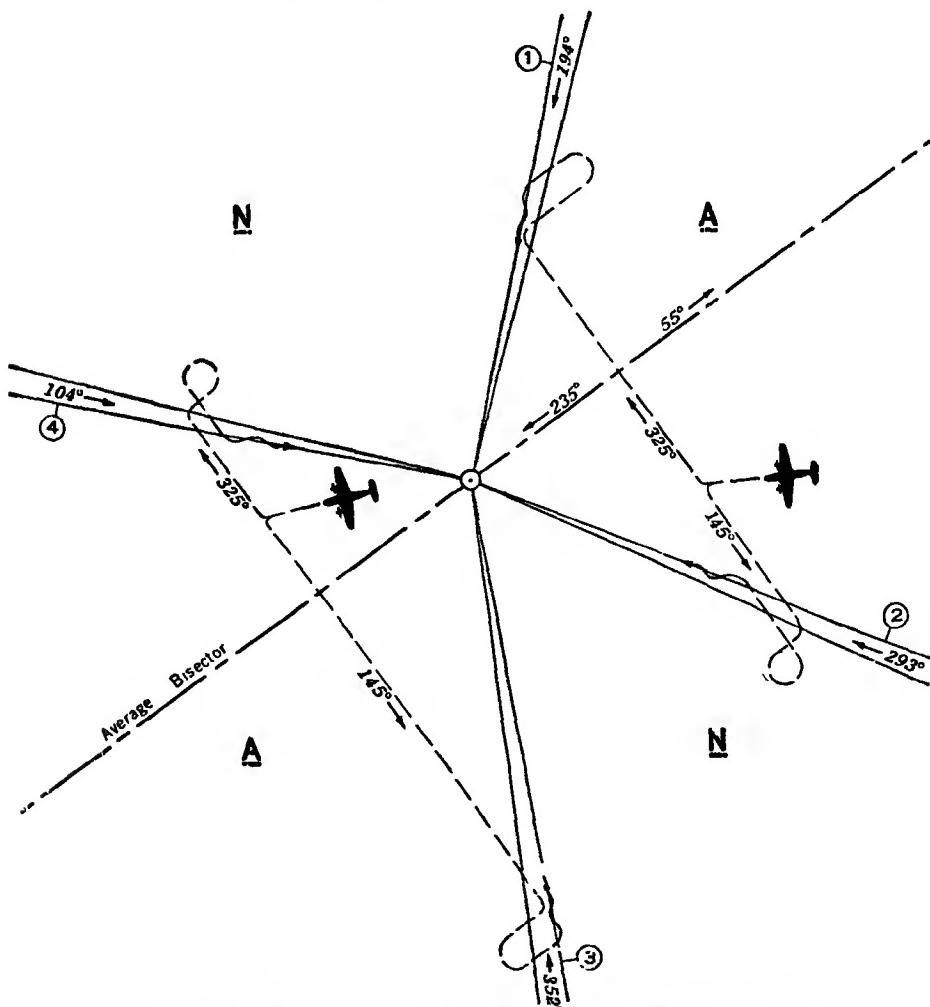
Figure 151.—Identification of the quadrant and range course; 90° turn method.

In figure 151 the average bisector of the two *A* quadrants is determined as follows: the bisector of the northeast quadrant is $(194° + 293°)$ $\div 2 = 243°$; the bisector of the southwest quadrant is $(352° + 104°) \div$ $2 = 228°$. The average of the two bisectors, then, is $(243° + 228°) \div 2$ $= 235°$, or its reciprocal, 055°. For greater ease in reading the compass or directional gyro during orientation procedure, bisectors are always determined to the nearest 5°.

An easier method for obtaining the average bisectors for both pairs of quadrants at once, is to add the bearings of the four beams exactly as they are printed on the chart, and divide the total by 4. The result is the bisector of one of the quadrants, and the average bisectors of the other quadrants are all at 90° intervals from it—always. For example (fig. 151),

<table>
<tr><td>194°</td><td>235° average bisector No. 1</td></tr>
<tr><td>293°</td><td>+ 90</td></tr>
<tr><td>352°</td><td>325° average bisector No. 2</td></tr>
<tr><td>104°</td><td>+ 90</td></tr>
<tr><td>4 | 943</td><td>055° average bisector No. 3</td></tr>
<tr><td>235° an average bisector</td><td>+ 90</td></tr>
<tr><td></td><td>145° average bisector No. 4</td></tr>
</table>

Bracketing a beam.—This is the process by which a pilot, having intercepted a beam not yet positively identified and at an angle only approximately known, endeavors to track the right-hand edge of the beam. The general procedure is illustrated in figure 152, on the easterly beam of the Harrisburg range station.

The compass heading upon intercepting the beam (355°) is noted and continued until the first off-course signal on the opposite side of the beam is received. A standard rate turn is then started to the left and continued until the first on-course signal is received (never exceeding 180°), when the compass heading is again noted (230°) and a standard rate turn to the right is begun. These two headings (*1a* and *1b*) constitute the first "bracket," the angle between them being 125°. The right turn should be continued until the first off-course signal is received and the bracket is reduced by about 25%: that is, until the compass heading is approximately 355° — 25% of 125°, or 325°. As soon as the edge of the beam has been reached, another standard rate turn to the left is begun and continued until the first on-course signal is again received and a compass heading of approximately 230° + 25% of 125°, or 260°, is reached. These two compass headings (*2a* and *2b*) are the second bracket, which has now been reduced to 65°. Each succeeding bracket is reduced by about 25%, the next bracket (*3a* and *3b*) being determined as 325°— 25% of 65° = 310°, and 260° + 25% of 65° = 275° The nearest 5° is used for each heading.

With practice, the heading required to maintain the right-hand edge of the beam can be determined within a few degrees after four or five

brackets have been flown; as skill is built up in interpreting and anticipating the signals, the amount of turning can be still further reduced. The difference between the heading required to maintain the right-
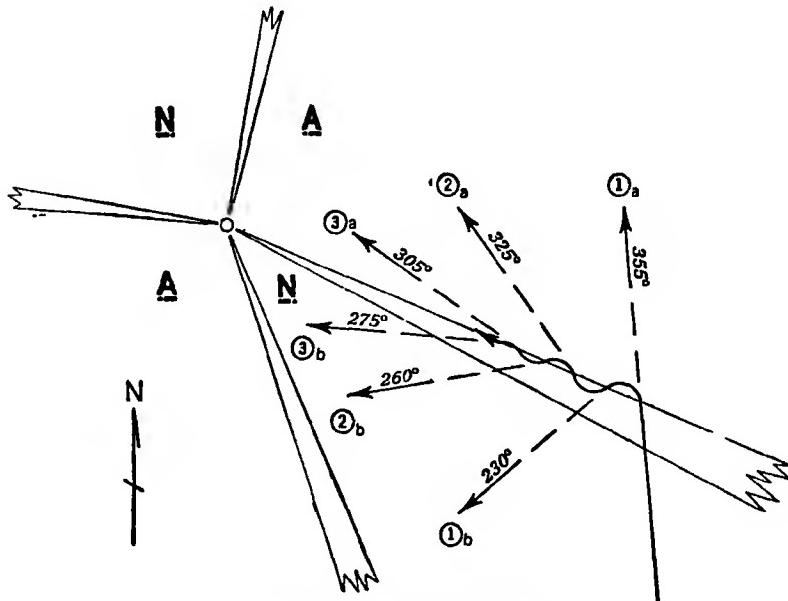
Figure 152.—Bracketing a beam.

hand edge of the beam and the charted bearing of the beam is the drift angle—information which the pilot should endeavor to have at all times.

METHODS OF ORIENTATION

There are several favored methods of quadrant identification and of finding the beam as quickly as possible, and the pilot should become thoroughly familiar with each of them in order to solve any given problem with the least delay. In the following discussion of these methods it will be assumed in each case that the pilot knows, from the signals received that he is in one of the two *A* quadrants of the Harrisburg radio range station, but does not know which one. In the various illustrations the beams are numbered for convenient reference in this text, but the numbers have no other significance.

The 90° turn method.—This was the first method of orientation to be developed. It is still popular because of its simplicity and uniformity, and is probably as good as any when within reasonable distance of a range which has quadrants approximately 90° each.

Under this system a heading is flown at right angles to the average bisector of the two possible quadrants (fig. 151). Since the average bisector is either 055° or 235°, the heading at right angles to it may be 145° or 325°. If the heading of 325° is chosen, then it is certain that beams 2 and 3 are somewhere behind the airplane. The pilot continues on

the heading of 325° until the on-course signal is received; through the beam until the first *N* signal on the other side is heard; then makes a 90° turn to the right.

He knows he has intercepted either beam 1 or beam 4. If it is beam 4, the *N* signal continues after the turn; if it is beam 1, the on-course signals will be heard first, then the *A* signal again. Thus the signals received definitely identify the beam intercepted.

After making the 90° turn to the right, if it is determined that beam 1 has been intercepted, the heading is maintained for 1 minute after leaving the on-course. A standard procedure turn of 180° is then made, away from the station, and that heading maintained until the far edge of the beam has been reached, after which the right-hand edge of the beam is bracketed and followed to the station.

If beam 4 has been intercepted, the same heading is maintained for 1 minute, as before; then a standard procedure turn of 270° is made, away from the station, and the new heading is maintained until the far edge of the beam is reached and bracketed. The right-hand edge of the beam is followed to the station, and from that point the pilot proceeds to the local airport or a more distant destination. When approaching the range station and close to it, pilots should fly *in* the on-course zone; pilots flying **from** a station are required by the Civil Air Regulations to fly to the right of the beam. When very near the station, care should be taken to hold the airplane level; if the airplane is permitted to bank, the signal heard will be the signal toward which the lead-in is pointed, rather than the signal in the zone where the airplane is being flown at the moment.

If the heading of 145° is chosen, rather than 325°, the procedure will still be the same as before, as shown in figure 151.

Where multiple courses are known to exist, instead of making the 90° turn as soon as the first *N* signal is heard, it is advisable to fly for some little distance before making the turn, selecting the true range course from among the several false ones encountered, if possible.

In the orientation example already given it was assumed that the pilot was near the center of an *A* quadrant; now suppose he is near enough to one of the beams that he can faintly hear the identification signal transmitted into the *N* quadrants as well as the identification signal transmitted into the *A* quadrants. This means that he is just east of beam 1, just north of beam 2, just west of beam 3, or just south of beam 4.

If he flies the 325° heading, at right angles to the average bisector of the quadrants, and the faint signal begins to fade, he knows he is flying away from the nearest beam, and that he is therefore just north of beam 2 or just west of beam 3; he makes a 180° turn, approaching the beam on the 145° heading, and the procedure from this point is identical with that illustrated in figure 151.

If he flies the 325° heading and the faint signal becomes stronger, the pilot knows he is approaching a beam, and that his position is therefore just east of beam 1 or just south of beam 4. He therefore continues

on the same heading, his further procedure being exactly as shown in the figure.

If flying entirely blind, the pilot should make sure that he is maintaining a safe altitude above the highest elevation in either A quadrant. The highest contour shown on the chart within reasonable distance of the Harrisburg station is 2,000 feet, but it must be assumed that elevations may extend almost to the next higher contour (2,500 feet on the sectional chart, or 3,000 feet on the regional chart), and an altitude well above that contour should be maintained until the position of the airplane can be definitely known. The Harrisburg instrument approach chart specifies a minimum altitude of 4,000 feet for all quadrants.

In quadrants not greatly exceeding 90°, this is a very dependable method, but if the airplane is in a quadrant where the courses meet at a wide angle (as the southwest quadrant of figure 151), on a heading at right angles to the average bisector of the quadrants it may be necessary to fly a considerable distance before picking up the beam, particularly if there is any appreciable amount of drift.

The parallel method.—Under this system the pilot flies a heading paralleling the average bisector of the two quadrants (instead of at right angles thereto), with the volume of his receiver as low as possible. If the signal fades out, he knows that he is flying away from the station; if the volume increases, he knows that he is approaching it. This procedure identifies the particular quadrant in which he is flying, unless some of the difficulties mentioned later prevent.

Referring to figure 153, if the pilot is flying a heading of 055° and the signal fades out, he knows he is in the easterly A quadrant with the station behind him. He makes a 180° turn and flies back toward the station as long as he flew away from it, checking the build-up of signal strength.

At Harrisburg the final approach should be made from the west, over beam 4. It would be desirable, therefore, to intercept beam 2 rather than beam 1, continuing on beam 2 past the cone of silence and out on beam 4, then making a procedure turn to reverse the direction of flight for the final approach along beam 2. A heading is therefore flown parallel to beam 1 until beam 2 is intercepted, when a turn is made toward the station and the right-hand edge of the beam is bracketed, after which the approach proceeds as outlined.

For some stations the signal strength is variable due to irregularities of the terrain, or night effect; the signals from these stations alternately increase and fade so that it is sometimes difficult to decide whether the volume is increasing or fading out. For this reason, the heading parallel to the average bisector should be maintained for at least 5 minutes. Also, in the case of "squeezed courses" (that is, when the beams are not 90° apart; see fig. 148) it is possible to fly away from a station and have the signals become stronger, instead of weaker.

Under any conditions, the greatest signal strength is found along the bisectors of the quadrants, the lowest signal strength along the edges, where the on-course zones are located. Therefore, flying parallel to the bisector, but at a considerable distance from it, the signal strength may decrease as the beam is approached, even though the station is nearer. If the decreased signal strength is due to approaching a beam, the double
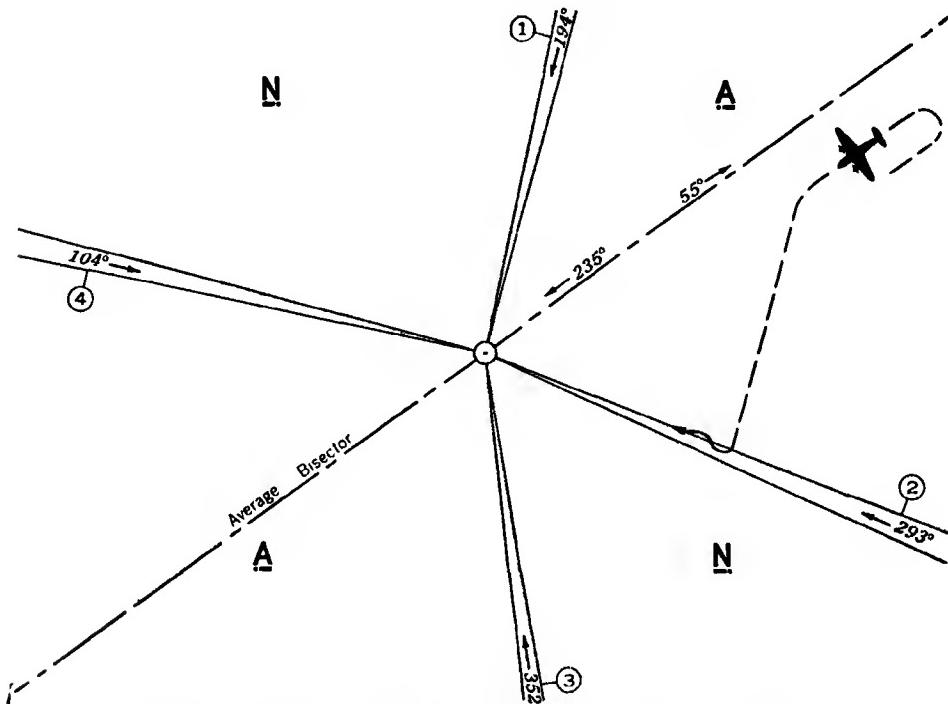
Figure 153. - Identification of the quadrant and range course; parallel method.

signals of the twilight zone should be heard upon turning up the volume. If the twilight signals are not heard with the increased volume, it is definitely known that the airplane is proceeding away from the station. In either case the quadrant is identified, the direction with respect to the station is known, and the pilot may proceed as outlined above and as illustrated in figure 153.

Other methods.—In any system of radio range orientation the essential steps are the identification of the quadrant and of the beam intercepted, and establishing the direction toward the station. It is believed that the methods just described are among the simplest yet developed and are representative of current practice, but a number of other methods have also been used.

For example, under the true fade-out method, the quadrant is identified as described under the "parallel method." A heading toward the station and parallel to the quadrant bisector is then flown until one of the two possible beams limiting the quadrant is intercepted, after which

the pilot turns left, brackets the right-hand edge of the beam, and follows it with volume as low as possible until a definite fade or build-up determines that he is flying away from or toward the station. If flying away, a procedure turn reverses the direction of flight and the on-course is followed to the station as a new point of departure.

As a slight variation of the method of the preceding paragraph, after intercepting the beam a 90° turn is made to the right, after which the procedure is identical with the 90° turn method, illustrated in figure 151.

In a narrow quadrant, instead of flying at right angles to the average bisector (the 90° turn method), or parallel to one of the courses in order to intercept the other (parallel method), some prefer to adopt a heading at right angles to the beam along which it is desired to approach the station. Upon intercepting the desired beam, the right-hand edge is bracketed and followed to the station.

If the two identification signals are heard, one strong and one weak, and, after identifying the quadrant and beginning the approach toward the chosen beam, the weak signal begins to fade, it is apparent that the pilot is flying away from the nearest beam, as well as from the station. A procedure turn is made at once; when the beam is intercepted it is bracketed as shown in figure 152, and followed toward the station.

Still other methods are used, many of which are well suited to a particular set of conditions but poorly adapted to others. In each case, as in other methods of navigation, the pilot must consider the known conditions and choose the procedure best suited to them.

Additional checks.—Having identified and bracketed the beam by any chosen method, the pilot must still be on the alert for every possible check on the accuracy of his solution. While flying the right-hand edge of the beam he should check the signal being received against the signal which his chart indicates he should be receiving. He should also check the magnetic course being made good (the compass heading rectified for deviation and wind) against the magnetic bearing of the beam on the chart, although from a check of the heading alone it is entirely possible to make a wrong deduction.

For example, after a period of uncertainty a pilot tunes in the Harrisburg range (fig. 153), and finds himself on a beam. The compass heading necessary to maintain the right-hand edge of the beam is determined as 012°. Deviation on this heading is 3° W. (fig. 54), making the magnetic heading 009°; the pilot therefore assumes that he is on beam 1, making a 5° allowance for a westerly wind. Unknown to the pilot, however, there is at the moment a strong east wind (30 mph will do it for an air speed of 100 mph), and he is actually on beam 3, making an allowance of 17° for an easterly wind. This can be checked from the fact that the pilot has the N signal on his right (instead of an A), and from the build-up of signal strength as the station is approached (instead of the anticipated fade).

Position from several stations.—In areas of converging airways and congested air traffic, where there are a number of radio range stations,

it is sometimes possible to determine position very closely and with little loss of time from the signals received from several stations. In figure 154, station 1 is tuned in, its identification signals checked, and it is determined that the airplane is in one of the A quadrants of the station. Next, station 2 is tuned, and the N signal is received. This alone almost certainly fixes the position in the northwest A quadrant of station 1 and north of the east course of station 2. Station 3 is then tuned in and an
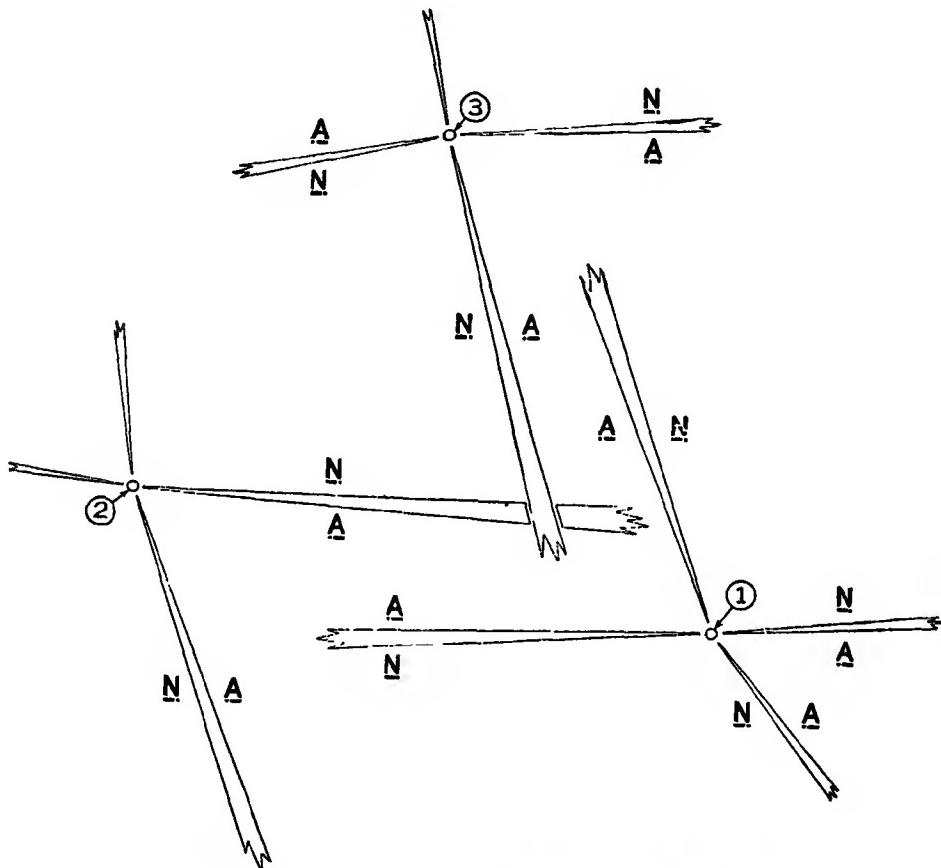
Figure 154.—Determination of position from several radio range stations.

N signal received, still further limiting the position of the airplane, and "X marks the spot," or at least the general area. Having determined position in this way, the pilot may approach the selected on-course by any preferred method, proceeding as already described.

AIDS TO ORIENTATION

The airport orientator is a valuable aid in all problems of quadrant and beam identification. In this instrument a circular chart showing the airport in relation to the courses of the radio range, with other pertinent

data, is directly attached to a disk member on the top of the directional gyro. Once the chart of the orientator has been properly aligned with the corresponding features on the ground, it remains so, as the result of gyroscopic action. Thereafter, regardless of the number of turns, a faithfully oriented picture of the attitude of the airplane with respect to the beams is given by the orientator chart—without mental effort on the part of the pilot.

With a radio compass using a visual indicator, quadrant identification is generally unnecessary, since the pilot may determine the direction of the station and fly directly to it, adopting a new heading from that point toward his destination.

ORIENTATION WITH VERY-HIGH-FREQUENCY RANGES

Installation of the very-high-frequency radio ranges, interrupted by the war, was resumed in the spring of 1944. These new ranges eliminate the need for working out orientation problems, each station providing one pair of courses to be indicated visually in the aircraft by a zero-center, left-right indicator; and another pair of courses, approximately at right angles to the visual courses, providing the familiar aural A and N signals. In this way a pilot flying an east-west airway, for example, could tell from the visual indicator whether he was on the beam, or to the right or left; from the aural signal he could tell whether the station was before or behind. The quadrant could always be definitely known, and the pilot could head directly for the beam along which it is desired to approach the range station.

CIVIL AIR REGULATIONS

In addition to the general problem of quadrant identification, certain other rules must be observed. For example, in order to prevent meeting aircraft flying in the opposite direction, it is important that pilots fly to the right of the beams. As an added safeguard, the Civil Air Regulations require that instrument flights along the airways be made at definite altitudes—in one direction at the odd thousand-foot levels (as 3,000, 5,000, or 7,000 feet above sea level), and in the opposite direction at the even thousand-foot levels (as 4,000, 6,000, or 8,000 feet). This insures that there will always be at least 1,000 feet vertical separation between planes flying in opposite directions. Definite altitudes are fixed for crossing another airway and, near control airports, "range approach channels" have been established, narrowing the civil airways (in effect) to 4 miles, instead of the usual 10 miles. This is necessary in congested areas to prevent local traffic from interfering with through or incoming traffic. A "floor" (minimum flight level) and "ceiling" (maximum flight level) have converted some range approach channels to "traffic tunnels." Other restrictions have been placed upon instrument flying within 5 miles of the center of an established civil airway, or within 25 miles of the center of a control zone of intersection. All these requirements are set forth in

detail in the Civil Air Regulations. Pilots are urged to obtain the latest copy of these regulations, and to become thoroughly familiar with them.

EFFECT OF WIND ON ORIENTATION

The effect of high winds on some of the orientation problems should be understood. Figure 155 is the same as figure 151 (the 90° turn
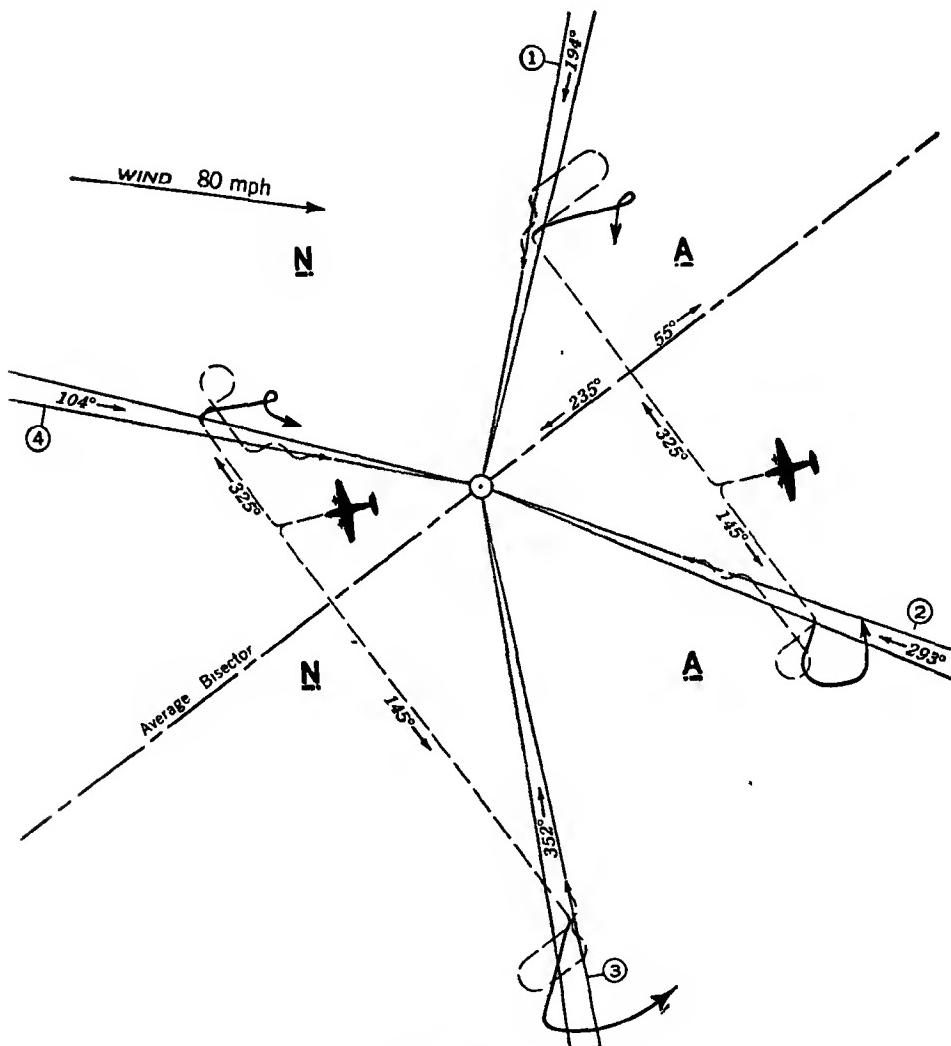
Figure 155.—Effect of wind on turns.

method of orientation), except that heavy solid lines have been added, showing the paths of the airplane at different points under the action of a high westerly wind. In order to illustrate the situation more clearly, a wind of approximately 80 miles an hour is assumed, with an air speed of only 110 miles an hour.

At position 1 in the figure, with wind of this proportion, the airplane will not follow the light broken line and return to the beam as intended, but will follow the heavy line.

At position 2, the case is not so bad, resulting only in increased distance from the station.

At position 3, upon turning back into the beam, drift would keep the pilot in the on-course zone so long he would probably doubt the whole procedure. If he continued with the problem, his track would be as shown. With the wind more nearly at right angles to his heading, the airplane might even be kept in the N quadrant by drift, leading the pilot to suppose he was at position 2.

At position 4, as at position 1, it is unlikely that the airplane would ever return to the beam.

While these are extreme conditions, intended to emphasize the effect of wind on turns, relatively high winds are often experienced—and it is at such times that one is most likely to need to work out an orientation problem. Consequently, pilots should make every effort to know the wind at all times during flight, and to visualize the effect of wind upon the headings being flown, or the maneuvers being performed.

RADIO MARKER BEACONS

Because of the needs of the armed forces, some of the less important range stations have been replaced with non-directional radio marker beacons. These are of power greater than 50 watts ("class H"), or power of 50 watts or less ("class MH"); the latter may ordinarily be received up to about 25 miles, while those of greater power may be received at correspondingly greater distances. The signal transmitted consists of the 2-letter identification of the station, repeated continuously with the least possible separation.

Designation of these beacons as H and MH signifies that they are intended primarily for Homing, which is discussed in connection with the use of the radio compass. Like the radio range stations, all H marker beacons operate continuously; MH beacons operate on request only.

Fan marker beacons operate on a frequency of 75 megacycles (75,000 kilocycles), and have no facilities for voice communication. Like the Z markers, they require an additional receiver. As their name and symbol imply, their radiated patterns extend vertically upward, like a fan across the airways. They are located at critical points along the airways, and on the approaches to major terminals. Figure 156 shows the fan markers located around the Pittsburgh range station. They are usually located no closer to a range station than about 20 miles, and are identified by a succession of single dashes, or by groups of two, three, or four dashes. The single-dash identification is always assigned to a course directed true north from a station, or to the first course in a clockwise direction therefrom; the groups of two, three, or four dashes are assigned respectively to the second, third, and fourth courses of the station, proceeding clockwise from true north. The signal of a fan marker beacon, then, identifies
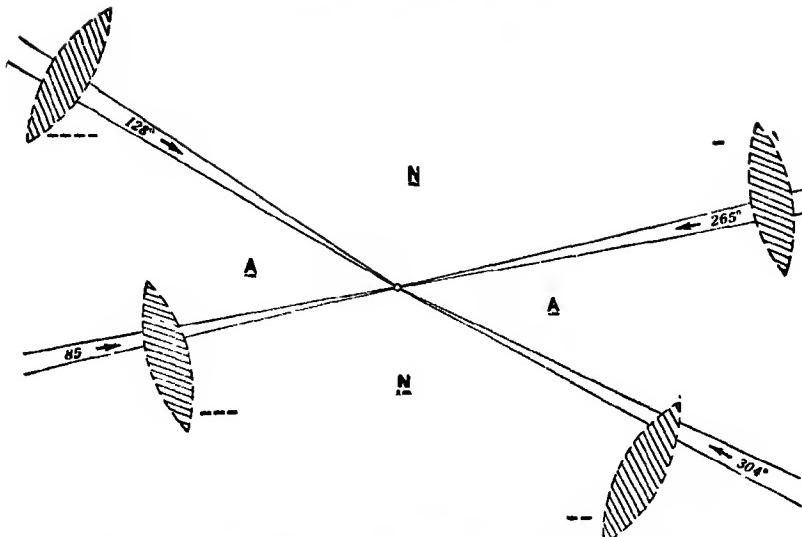
Figure 156 – Fan marker beacons around the Pittsburgh radio range station.

a particular course of a range, and also a position along that course; it therefore definitely fixes the location of the airplane.

Low powered fan markers may also be located at distances not exceeding 10 miles from a range station. They are identified by the groups of one, two, three, or four dashes already described. When there is a low

Flight path of an aircraft operating on an instrument flight rule flight plan and being held at a radio fix shall follow the right edge of the on course signal of the specified leg of the appropriate radio range The aircraft shall hold between the designated holding point and point 4 minutes flying time therefrom in the direction specified, starting procedure turns at the holding point and point 4 minutes therefrom Unless prevented by obstructions or unless otherwise advised by an Airway Traffic Control Center or Civil Aeronautics Administration Airport Traffic Control Tower, the initial turn of a procedure turn shall be made to the left when flying away from the range station and to the right when flying toward the range station The point to be used as the designated holding point will be identified in the traffic clearance which contains instructions for the aircraft to hold

"HOLD ON THE EAST LEG OF SMITHVILLE RANGE BETWEEN JASON INTERSECTION AND A POINT FOUR MINUTES EAST UNTIL 10 35 ETC "

"HOLD ON THE EAST LEG OF THE DAWN RANGE BETWEEN STATION AND POINT FOUR MINUTES EAST UNTIL 10.35 ETC."

"HOLD ON EAST AND WEST LEGS OF CLEVELAND RANGE BETWEEN POINTS FOUR MINUTES EAST AND FOUR MINUTES WEST FROM STATION UNTIL ADVISED BY TOWER ETC."
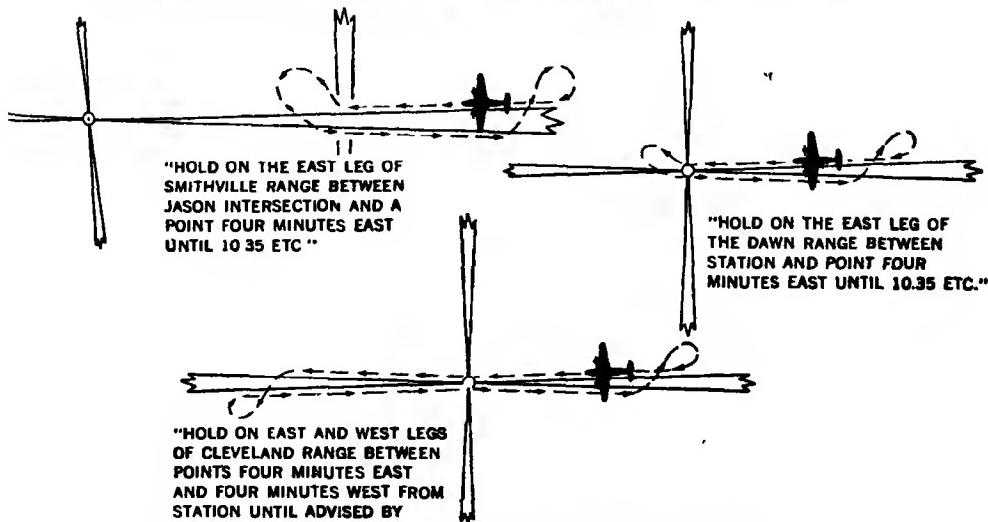
Figure 157.—Procedures followed by aircraft holding at radio fixes.

powered marker close to the station and a normal fan marker farther from the station on the same beam, the proper number of dashes for the second from the station is preceded by two dots. For example, a low powered marker on the north-westerly beam from a station has an identification signal of four dashes (_ _ _ _). A fan marker of normal power farther out on the same beam is identified by the same number of dashes, preceded by two dots (.._ _ _ _).

In thick weather, when visual observations cannot be made, ground speed can be determined by noting the time required to reach a given marker beacon, or from the elapsed time between passing successive marker beacons, range stations, or cross-beams from other radio range stations. Such points are known as "radio fixes," and are important in the system of airway traffic control. Typical procedures to be followed by aircraft holding at a radio fix are illustrated in figure 157.

RADIO DIRECTION FINDING

There are several types of equipment under this general head. In each case, however, use is made of the directional characteristics of a loop antenna. The loop may be either fixed or rotatable, and signals may be received aurally or visually, or both.

An installation using a fixed loop and visual indicator is properly known as a radio compass. With this arrangement, as long as the airplane is headed directly toward a radio station the needle of the indicator remains centered; headings to the right or left of the station result in a corresponding deflection of the needle. The radio compass is used chiefly as a "homing" device, and bearings of radio stations off the line of flight may be obtained only by turning the airplane toward the station and noting the magnetic compass heading when the indicator needle is centered.

An installation using a rotatable loop is generally known as a "radio direction finder." With the rotatable loop, bearings may be obtained without turning the airplane itself. The loop is rotated until the position of minimum signal strength, or "null," is obtained; the bearing of the station may then be read from a graduated dial. On some instruments allowance may be made for variation and deviation, so that true bearings may be read directly from the instrument, ready for plotting on the chart. On many installations it is only necessary to tune in the station desired; the loop is then rotated automatically, and the indicator points continuously toward the station. This type is known as the "automatic direction finder."

Both the radio compass and the direction finder are valuable aids when flying the radio range system. For example, if a pilot is flying a range course and is able at the same time to obtain the bearing of some off-course radio station, the intersection of this bearing with the range course, when plotted on the chart, definitely fixes the position of the airplane along the course at the moment the observation was made. Or if

the pilot is appreciably off course he may identify the quadrant in which he is flying by means of the observed bearing to the radio station. This also informs him of the location of the equisignal zones, and he may proceed to the station without the extra flying required by other methods.

ERRORS IN RADIO DIRECTION FINDING

Like the magnetic compass, and for much the same reasons, the radio compass is usually subject to deviation on some headings. This may be determined and applied in exactly the same way that deviation of the magnetic compass is determined and applied. In the more recent installations a correction for deviation is incorporated in the instruments themselves, and bearings may be used directly as read. Obviously, this is to be preferred.

It should be remembered that radio compass bearings are subject to the same distortions that produce multiple radio range courses in mountainous country. They are also affected by interference between stations broadcasting on the same frequency, and by "night effect."

ORIENTATION WITH THE RADIO COMPASS

Under certain atmospheric conditions it is sometimes necessary to disconnect the "sense antenna," without which it is impossible to determine directly whether a radio station is before or behind the airplane. That is, it is impossible to know whether the station is in the direction of the indicated bearing or of its reciprocal. It then becomes necessary to work an orientation problem in much the same manner as that used with the radio ranges.
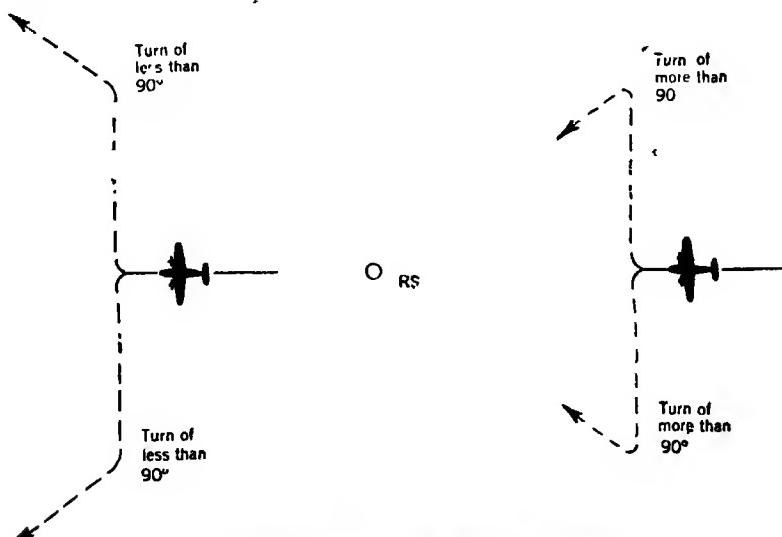
Figure 158.—Orientation with the radio compass.

In figure 158, suppose that an airplane is being flown on a heading of 270° true when the direction of a radio station RS is determined as

either directly ahead or directly behind. A 90° turn is made, either to the right or left, and the new heading is maintained for a period of from 3 to 10 minutes, depending on the ground speed and the distance from the station. The aircraft is then turned again until the radio compass indicator is centered; if the turn required is *more* than 90°, the station is ahead; if the turn is less than 90° the station is behind. This can easily be checked by reference to the figure.

HOMING WITH THE RADIO COMPASS

Use of the radio compass merely as an auxiliary for radio-range flying is a very limited application of this equipment; it is as useful for direction finding and position determination off the airways as on the radio range system itself. With it, pilots are enabled to tune in any broadcasting station of which the position is known—commercial or Government—and fly directly to the station selected, merely by heading the airplane so as to keep the pointer of the indicator centered. With the Lambert and stereographic projections, a straight line drawn on the chart from any given position to the radio station in question represents
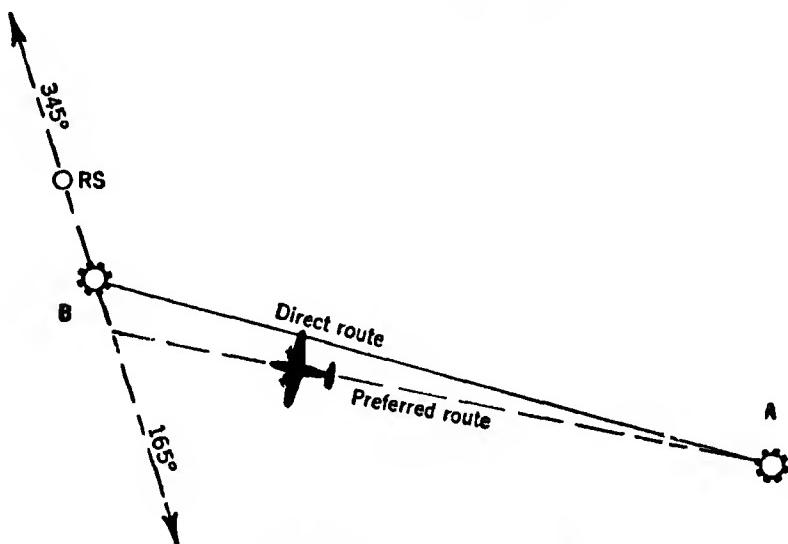
Figure 159.—Radio compass approach.

the no-wind track the airplane would make good over the ground in flying to the station. With the Mercator projection a correction must be applied, except in areas near the equator.

When the radio station is a little to one side or the other of the direct route to the airport of destination, it is good practice, as a rule, to approach the radio station on a heading in line with the bearing between the radio station and the airport, as illustrated in figure 159. This makes it relatively easy to locate the airport, even in thick weather. In the event that the airport is not located at first, the reciprocal heading is flown from the radio station, with a good chance of picking up the airport this time.

PLOTTING RADIO BEARINGS ON LAMBERT AND STEREOGRAPHIC CHARTS

If the pilot wishes only to determine his position, rather than to fly to the station, he may obtain the true bearing of the station and plot it on the chart; the intersection of this bearing with a bearing from a second station determines the position of the airplane. A bearing from a third station, when available, affords a more positive fix, and serves as a check on the first bearings. As a result of the various errors involved, the three bearings will seldom meet in a point, but the center of the triangle formed by the plotted bearings may be accepted as the true position.

The method of plotting a bearing on the chart with a popular type of protractor is illustrated in figure 160. A pilot in the vicinity of the point P observed the bearing X of the radio station RS. The observed bearing is measured at the meridian nearest the probable position, and
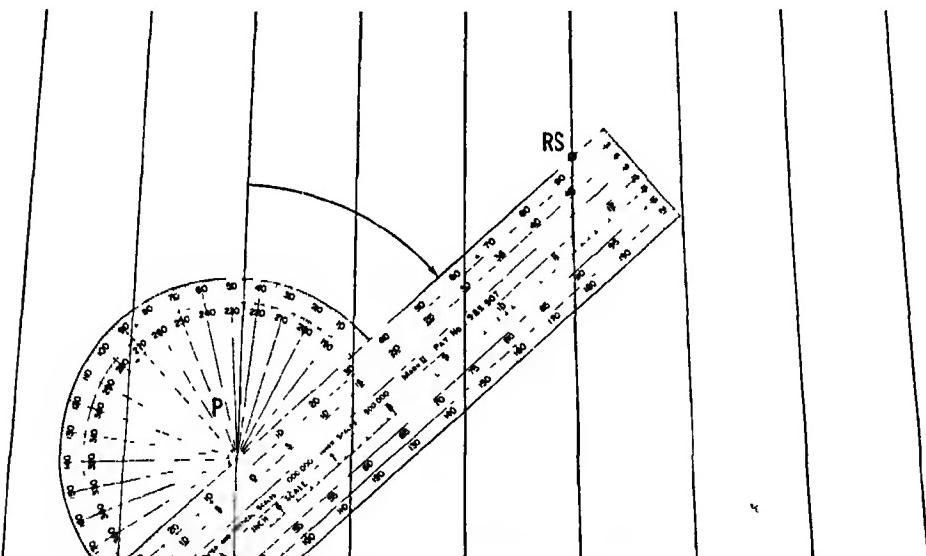
Figure 160.—Plotting a radio bearing on a Lambert chart.

the protractor is moved along the meridian until its plotting edge passes through the radio station, being careful to keep the protractor at the original angle. A line from RS along the edge of the protractor is the desired bearing. If the arm of the protractor is not long enough to reach from the assumed position to the radio station, the observed bearing may be plotted from any convenient point on the meridian nearest the assumed position; a line drawn parallel thereto from the radio station represents the bearing.

In figure 161, a pilot flying in the vicinity of F determines the bearing X of the station RS. At the same time, the naval radio direction finder station RC measures the bearing Y of the aircraft from the station and

reports it to the pilot by radio. The pilot was uncertain of his position,
but assumed that he was near the point *P*, and plotted the bearing *X* with
the meridian nearest that position. The bearing *Y*, plotted from *RC* as
shown, intersects the first bearing at *F*, fixing the location of the aircraft
at that point.
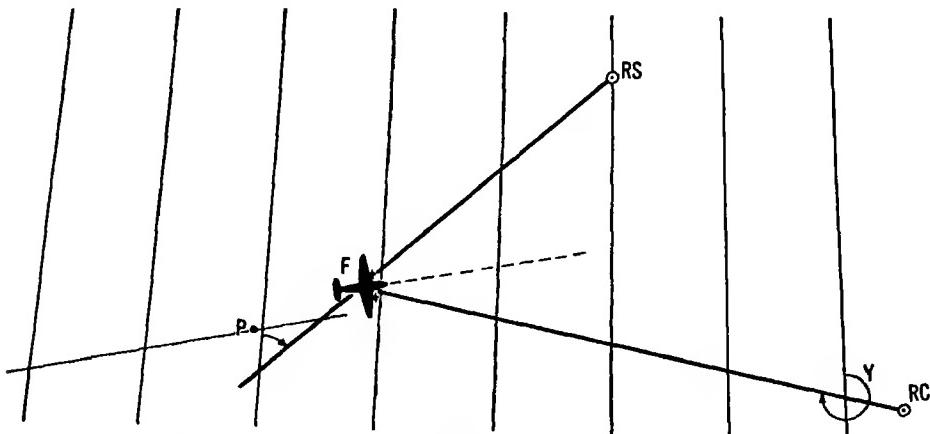
Figure 161.—Position determination from two or more radio bearings.

In the example just given, the radio direction finder station was
introduced in order to illustrate the plotting of bearings so determined.
Also, for the sake of simplicity it was assumed that the bearing of the
airplane was determined there at the same time that the pilot observed
the bearing of the other radio station; in practice, this could scarcely be
the case.

A RUNNING FIX

Under favorable conditions, and with modern equipment, bearings on
two or three radio stations may be determined in less than a minute. In
this case it may be considered for all practical purposes that the bearings
were taken at the same instant.

When any considerable time elapses between the determination of the
two bearings, the position of the airplane is determined by what is known
as a "running fix." For example, figure 162 illustrates the same problem
as that of figure 161, except that the direction finder station *RC* is re-
placed by a second radio station *R*, and that after obtaining the bearing
X, the airplane flew due east (true) for a period of 10 minutes at a
ground speed of 180 mph before obtaining the bearing *Y* of the second
radio station.

In 10 minutes at a ground speed of 180 mph the airplane will have
traveled 30 miles. From any convenient point " *Z* on the line representing
the bearing to the first station, draw a line *ZZ'* running due east a dis-

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* From a theoretical standpoint, the nearer the point selected is to the correct position of the airplane
at the time of the first observation, the more accurate will be the results. In practice, however, "any
convenient point" will be well within any desired limits of accuracy.

tance of 30 miles. Then through the point Z' draw a line parallel to the original bearing line; the intersection of this line with the plotted bearing of the second radio station fixes the position of the airplane at the time the second bearing was obtained. Note that the bearing Y is plotted with the next meridian east of the one used for plotting the bearing X, since the assumed position has also moved 30 miles eastward, and is now nearer to the more easterly meridian.
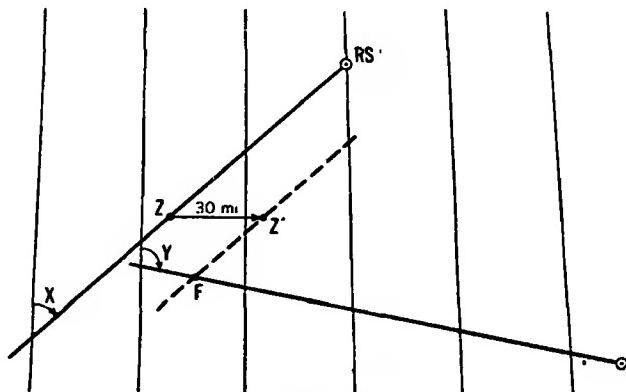
Figure 162 A "running fix" from radio bearings.

If, after carrying forward the bearing X, it is found that the assumed position is greatly in error—say, by one degree of longitude [7] or more—a more accurate determination of position may be had by replotting the observed bearings at the meridian nearest the fix. In the second plotting of the bearings the line representing the bearing of the first radio station must still be carried forward to obtain the fix, exactly as in the first plotting.[8] See example 3, p. 243.

BEARING FROM STATION ON ADJOINING CHART

When the radio station observed falls within the limits of the chart being used, the method illustrated in figure 161—plotting the observed bearing from the meridian nearest the assumed position P through the radio station—is the simplest and most accurate. If the sectional charts are used for this purpose it is quite likely that the station observed may be off the chart. In this case, it is preferable to change to a smaller scale chart which includes both the station and the assumed position. If only the large scale charts are at hand, it will be necessary to plot the bearing directly from the radio station on the adjoining chart to the border, and

[7] An error in the latitude of the assumed position, however great, will not affect the accuracy of the result.

[8] For utmost precision only the last bearing should be plotted at the meridian nearest the fix; the first bearing should be plotted at the meridian nearest the point where it was observed, and then carried forward. This meridian could be found by carrying the fix *backward* the dead reckoning distance and direction made good between the two bearings; however, if both bearings are plotted at the same meridian and the first bearing is then carried forward, the maximum error in the fix, with a run of 50 miles or more between the two observations, would only be about 1 mile for every 100 miles distance from the radio station, which is too small to justify the longer procedure. Regardless of the meridian selected for plotting the first bearing the line must still be carried forward as described above.

to measure the angle at which the plotted bearing crosses the last meridian before reaching the border; the point of crossing that meridian must then be transferred to the other chart, and the bearing line continued at the same angle.

To plot the bearing directly from the station some pilots add (or subtract) 180° and plot the reciprocal bearing, but this is inaccurate. Due to convergence of the meridians (see p. 46) the bearing at the radio station is never the reciprocal of the bearing observed at the airplane. The bearing to be plotted from the radio station is obtained as follows:

1. To the bearing observed at the airplane, add (or subtract) 180°.

2. If the AIRPLANE is WEST of the radio station ADD the correction for convergence; if the airplane is east of the station, subtract the correction.

It will be noted that the foregoing rules follow the same form as the rule for applying magnetic variation, and that the rule begins with the airplane, where the bearings are actually determined.

The correction for convergence is the difference of longitude in degrees, multiplied by the convergence for the proper projection band; see table 3, p. 47. Sufficient accuracy will generally be obtained if convergence is used to the nearest tenth of a degree. Thus, for the United States it is only necessary to multiply the difference of longitude by 0.6; in Alaska, 0.9 will be close enough for the purpose. Normally, it should be unnecessary to plot a bearing from a station on an adjoining chart; if for any special reason it should be needed often, a brief table can quickly be prepared showing the correction to be applied for each degree of difference of longitude.

SPECIAL CHARTS FOR RADIO DIRECTION FINDING

The preceding discussion and methods apply to all standard aeronautical charts on the Lambert and stereographic projections, and are essential to a clear understanding of the subject. They apply also to the aeronautical charts on the Mercator projection in the narrow band near the equator, shown in figure 33; they do not apply to Mercator charts in high latitudes. The scale of both the sectional and regional charts often is too large for convenient use in this work, while the scale of the planning charts is generally too small. To bridge this gap and to provide the quickest and easiest means of position-finding from radio bearings, the series of aeronautical charts for radio direction finding in the United States was designed.

These special charts are at a scale of 1:2,000,000, six charts (with generous overlaps) being required to cover the United States (see fig. 9). As a result, it is seldom, if ever, necessary to plot a bearing from a station on an adjoining chart.

Around each radio range station there is a special compass rose (see fig. 76 and pl. II) oriented to the magnetic meridian instead of the true meridian. These compass roses are intended primarily for plotting reciprocal bearings, and therefore the larger (outer) figures read from 0

at magnetic south. When plotting bearings from these stations it is not necessary to add or subtract 180° to obtain a reciprocal bearing. It is only necessary to draw a line from the radio station through the graduation corresponding to the observed magnetic bearing (using the outer figures). The line so drawn is the desired line of position. See example 4, p. 243.

Some inaccuracy is introduced by this method, since the magnetic variation at the station is used, rather than the variation at the point of observation (that is, at the position of the airplane) ; also, no correction is made for convergence of the meridians. If utmost accuracy is required, corrections may be applied for these two items. The correction for convergence has already been described. The difference between the magnetic variation at the airplane and at the radio station should be added when westerly variation increases toward the station, or when easterly variation decreases toward the station; subtracted if the reverse; see example 5, p. 244. In the majority of cases in the United States, this correction will be of the same sign as the correction for convergence.

It may be easier for some to understand the application of the correction for the difference in variation by thinking of variation as being a maximum in the eastern United States and gradually decreasing through zero (at the agonic line) to a minimum on the west coast. The rule may then be stated as follows: ADD the difference if the variation at the airplane is LESS than at the radio station; subtract if the variation at the airplane is greater.

When planning these charts only magnetic bearings could be directly obtained, and it was decided that the rapid and frequent determination of approximate positions was more desirable than more tedious though more exact methods—particularly in view of the limited accuracy of radio bearings yet attainable. If greater accuracy is desired, instead of applying the above corrections it may be easier to disregard the compass roses altogether, and plot true bearings with a protractor, by the methods already described.

A number of commercial radio broadcasting stations, selected with regard to their suitability for radio direction finding, also appear on these charts. Because of congestion it is impractical to print compass roses around all these stations, and bearings from them must be plotted in the conventional manner described in the preceding section.

PLOTTING RADIO BEARINGS ON MERCATOR CHARTS

Since the normal path of a radio bearing is always a great circle, it is obvious that it can only be represented on a Mercator chart by a curved line. In order to be able to plot the bearing as a straight line (rhumb line), a correction must be applied that is equal to the angular difference between the rhumb line and the tangent to the curve representing on the Mercator projection the great circle between the airplane and the radio station. See figure 42. For distances less than 100 miles this correction is

usually negligible, the maximum error not exceeding **1°** except in high latitudes.

In north latitudes and for bearings taken on board the airplane, if the airplane is east of the radio station the correction is to be subtracted; if the airplane is west, the correction is to be added. In the southern hemisphere the application is reversed in each case. These rules are often stated in the following form:

For bearings measured at the airplane, in north latitudes,

$$\text{when airplane is } \frac{\text{east}}{\text{west}} \text{ of station } \frac{\text{subtract}}{\text{add}} ;$$

In south latitudes,

$$\text{when airplane is } \frac{\text{east}}{\text{west}} \text{ of station } \frac{\text{dd}}{\text{subtract}}$$

For bearings measured at a ground station, all the foregoing rules are reversed.

Instead of trying to remember these rather complex rules, most pilots will find it easier to work from a mental picture or sketch similar to figure 42. In the northern hemisphere a great circle on the Mercator projection always curves northward, above the rhumb line and *away from the equator*. In south latitudes a great circle curves southward, below the rhumb line and *away from the equator*. From such a sketch it is always easy to know when the correction should be added and when subtracted.

The correction to be applied is equal to one-half the difference in longitude times the sine of the middle latitude between the airplane and the station. Table 5 shows the corrections to the nearest half-degree, from the equator to latitude 75°, and for differences of longitude up to 10°. The correction may be more conveniently determined with a computer, as described on p. 194.

TABLE 5.—*Corrections to radio bearings on Mercator charts, to the nearest half-degree*

Mid-Lat	Difference of longitude in degrees									
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
0°	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5°	0.0	0.0	0 0	0.0	0.0	0.5	0.5	0.5	0.5	0.5
10°	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0
15°	0.0	0.5	0 5	0.5	0.5	1.0	1.0	1.0	1.0	1.5
20°	0.0	0.5	0.5	0 5	1.0	1.0	1.0	1.5	1.5	1.5
25°	0.0	0.5	0.5	1 0	1 0	1.5	1.5	1.5	2.0	2.0
30°	0.5	0.5	1.0	1 0	1.5	1.5	2.0	2.0	2.5	2.5
35°	0.5	0.5	1.0	1 0	1.5	1.5	2.0	2.5	2.5	3.0
40°	0.5	0.5	1 0	1.5	1.5	2.0	2.0	2.5	3.0	3.0
45°	0.5	0.5	1 0	1 5	2.0	2.0	2.5	3.0	3.0	3.5
50°	0.5	1.0	1 0	1.5	2.0	2.5	2.5	3.0	3.5	4.0
55°	0 5	1 0	1.0	1 5	2.0	2.5	3.0	3.5	3.5	4.0
60°	0.5	1.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5
65°	0.5	1.0	1.5	2 0	2.5	2.5	3.0	3.5	4.0	4.5
70°	0.5	1.0	1 5	2 0	2.5	3.0	3.5	4.0	4.0	4.5
75°	0.5	1.0	1.5	2 0	2.5	3.0	3.5	4.0	4.5	5.0

RELATIVE BEARINGS

This section and those that follow are applicable to all projections alike, being the result of the equipment available and the nature of radio navigation itself.

With much of the earlier equipment it was possible to observe only "relative bearings"—that is, the bearing of a station with reference to the heading of the aircraft at the moment. Relative bearings were measured from 0° in the direction of the heading, up to 180° toward the right or left. In order to plot a bearing on the chart, it was necessary to rectify the compass heading for deviation and variation, and then to ADD relative BEARINGS for stations to the RIGHT—subtracting them for stations to the left.

In order to avoid confusion as to when to add and subtract, the right semicircle of some radio direction finder dials was colored green, the left semicircle red. The rule then was, *ADD GREEN* bearings; subtract red. For bearings near 360°, it was sometimes necessary to add or subtract 360° in order to perform the required operations.

With more recent equipment, provision is made for setting the dials for the heading being flown; allowance is even made for variation and deviation, so that the true bearing of the station may be read directly, from 0° around to 360° in a clockwise direction, ready to plot on the chart.

THE RADIO COMPASS AND WIND

In radio compass navigation, as in all other methods, wind is the principal complicating factor; once understood, however, the proper allowance for wind can be made and the pilot may proceed with reasonable certainty even though the ground is not visible.

As already stated, the radio compass with nonrotatable loop is used chiefly as a homing device, and cross bearings can be obtained only by turning the airplane itself to head toward the station in question. It is not without its advantages for the pilot-navigator, but with it the allowance for wind is more complicated and precise navigation a little more difficult than with the rotatable loop.

When using the radio compass solely as a homing device, even though the pilot heads his airplane directly for the radio station *RS* of figure 163, under the effect of cross winds the airplane will follow the round-about broken line of the figure instead of the direct route.

From the standpoint of the added distance alone this is often unimportant, since it seldom requires appreciably more time to fly the round-about course than to head into the wind and crab along the intended track at reduced ground speed; on the other hand, it is always desirable to know with reasonable precision the track being made good. At times this is absolutely essential in order to keep the airplane over favorable terrain or to avoid dangerous flying conditions. Furthermore, as is usually the case, more precise methods of navigation do result in some saving of flying time.

In view of the wind factor, precise navigation with the radio compass is possible only in conjunction with a stable magnetic compass, or with a directional gyro. To illustrate, suppose that a pilot leaves a point E and proceeds toward a distant radio station R. From the chart he knows that the true course from E to R is 090°. With a true heading of 090°, he soon finds from his radio compass that he has drifted to the left. Heading
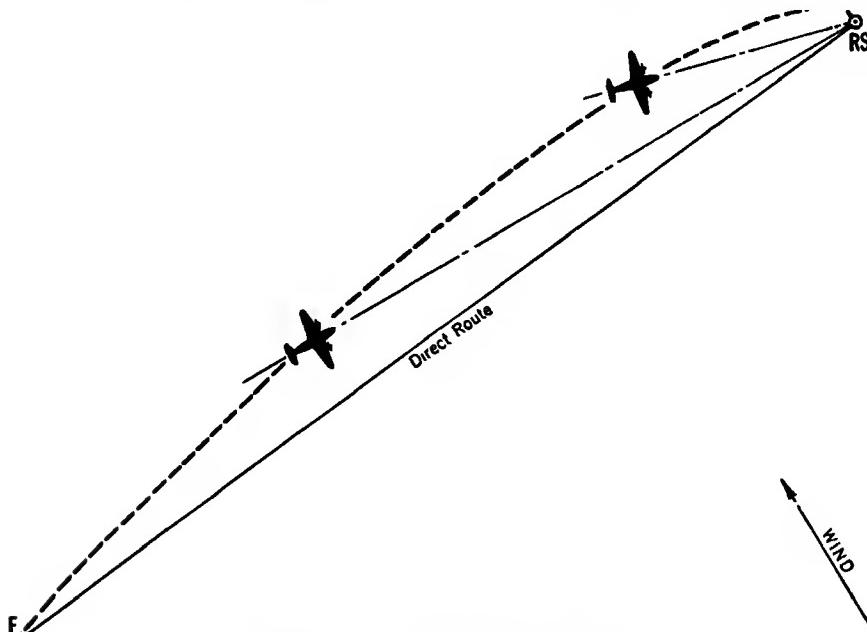
Figure 163.—The radio compass and wind effect.

slightly into the wind, after another period of flying he finds (by turning for a moment to the original heading of 090°) that he has now returned to the direct route; this means that he has made more allowance for wind than is necessary in order only to maintain the intended track, so he assumes a heading between the first and second. After a period of flight on this intermediate heading, he again turns momentarily to the original heading of 090°, just long enough to determine from the radio compass that he is still on the direct line to the station at R; this indicates that he is making the proper allowance for wind, and he turns back to the intermediate heading. Subsequent checks made by turning the airplane momentarily to the original heading of 090° will keep him advised of any deviation from the direct route and enable him to make any further changes in heading that may prove necessary. An additional check is found in the fact that while the correct heading is maintained the pointer of the radio compass will read off-center. As long as it remains off-center by the same amount, it may be considered that the airplane is making good the direct track to the station. The procedure is the same whether flying toward a radio station, or flying away from a station.

If the airplane is proceeding from a radio station as a point of departure, using the radio compass as a homing device (flying away from

home), and the visual indicator shows a deviation from the direct route the drift angle may be determined simply by heading the airplane so as to center the indicator and noting the difference in degrees from the original heading. While one drift angle cannot determine a position, if this angle is plotted on the chart and the estimated distance made good is scaled along it, an approximate position is obtained which may be of some assistance.

The drift angle, applied to the heading, determines the track. When the ground speed can be known—by direct observation, by radio cross-bearings, by radio markers, or by other means—the current wind direction and velocity can be found readily from the true heading and air speed, together with the track and ground speed. With this information, of course, more precise navigation is possible for the remainder of the flight.

If the route being followed is a long one, as the route from St. Louis to Minot (fig. 81), the heading must be changed to conform to the change in true course as the end of each succeeding section is reached.[9] If the wind were constant, the steering perfect, and the airplane started on the proper heading, this would not be necessary; as long as the indicator remained centered the airplane would track the great circle toward the station, and the ever-changing direction of the bearing (fig. 35) would be automatically registered by the compass or gyro. Since such ideal conditions do not exist in practice, it is necessary to make the changes periodically, as suggested.

THE RADIO DIRECTION FINDER AND WIND

The foregoing applies to the nonrotatable loop antenna; when using the rotatable loop the procedure is simpler. Assume that the aircraft is homing toward the same radio station R as in the preceding section, with the true heading of 090° indicated both by the magnetic compass and by the radio direction finder. Gradually the airplane drifts to the left, the compass heading remaining unchanged while the bearing indicated by the direction finder increases to 095°.

In a first attempt to correct for wind, the aircraft is turned 10° to the right, and the new true heading of 100° is set on the direction finder, after which the direction of the radio station is again indicated as 95°. As flight is continued on the true heading of 100°, the bearing indicated by the direction finder gradually decreases to 090°, showing that the airplane has returned to the original track, and that the heading of 10° into the wind is more than is required merely to maintain the direct track.

As a second attempt, therefore, a true heading of 095° is adopted, and is set on the radio direction finder. With this heading it is found that the bearing of the station remains just about constant at 090°. This is evidence that the correct allowance is being made for wind, and that the direct

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[9] In theory there is some difficulty in the combined use of a compass (or gyro) and the radio compass, since the latter determines a bearing at a point while the former determines a course; however, as explained on p 45, when courses are properly determined the departure of the course from the straight line representing the bearing is negligible.

track to the station is being maintained. The difference between the true heading of the aircraft and the true bearing of the station is the wind correction angle.

In theory, if the distance between the airplane and the radio station is great, the bearing will increase slightly as the station is approached (when flying east) because of convergence. That is, if the airplane is 4° of longitude west of the station (in the United States) and the bearing of the station is 090°, as the airplane follows the direct route to the station the bearing will increase to 090°.6 at 3° of longitude from the station, to 091°.2 at 2°, and 091°.8 at 1° from the station. Because of inequalities in wind and steering, inaccuracies of observation, and personal factors, this is not likely to be detected in practice.

Under unusual conditions, if the airplane is already close to dangerous topography, instead of returning to the intended track as described above, it may even be desirable to circle back, reaching the plotted route at a position nearer the starting point. The arrival over the intended route
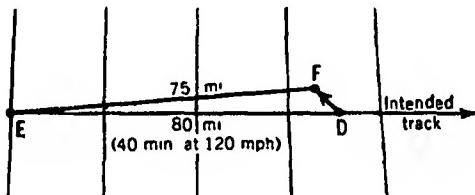
Figure 164—Determination of wind by radio direction finder.

must be determined by the radio direction finder in conjunction with the gyro or magnetic compass.

When a fix has been obtained by cross bearings, as described on page 224, the wind direction and velocity may be obtained graphically, if desired. In figure 164, after flying due east from E for a period of 40 minutes and at an air speed of 120 mph, a fix was obtained at F. From the chart it is found that F scales 75 miles from E. ED represents the heading and air speed of the airplane, EF the track and ground speed, and the angle at E the drift angle. DF represents the wind direction and velocity, which is found to scale 7 miles, and is from the southeast (135°); since the 7-mile drift occurred in a period of 40 minutes, the wind velocity is 10 mph.

If the airplane is proceeding from a radio station as a point of departure, using the direction finder, and a departure from the direct route is noted, the difference between the true heading (determined from the magnetic compass) and the true bearing of the station (determined from the radio direction finder) is the drift angle.

A RADIO LINE OF POSITION

In the preceding sections reference has been made to a radio line of position. While a full understanding of this term is not strictly necessary, it should help to clarify the problem and may be useful under certain conditions.

If the bearing of an airplane is determined at a radio station, and plotted at the meridian of the station on a Lambert chart, then the straight line between the station and the airplane is a radio line of position. The radio station is definitely fixed on the chart, and the bearing of the airplane is accurately known; the plotted bearing, therefore, is positively determined as the line on which the airplane is located. This statement is limited only by the accuracy with which a straight line on the Lambert projection represents a true great circle—and within practical limits this error is negligible.

If the bearing X of the radio station R (fig. 165), is determined at the airplane and plotted on a Lambert chart, at the meridian nearest the *assumed* position of the airplane, then the point P on the meridian is only a point on the radio line of position. There is also a point P_1 on another
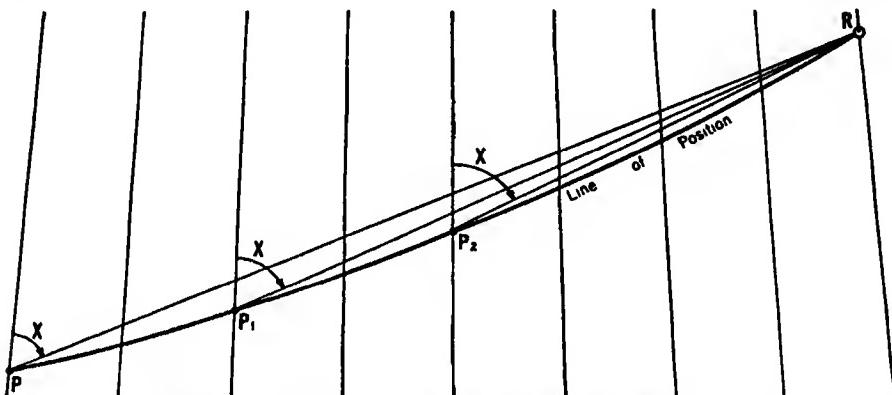
Figure 165. –A radio line of position from bearing determined at airplane.

meridian where the same bearing might have been observed, a similar point P_2 on still another meridian, and so on; the airplane might have been located at any point on the curved line (greatly exaggerated) drawn through these points where the bearing of R is the same. Strictly speaking, then, this curved line is the radio line of position as determined at the uncertain location of the airplane.

If strictest accuracy in plotting is required, the radio line of position may be easily obtained on a Lambert chart by plotting the observed bearing at two or three meridians on each side of the assumed position and drawing a curved line through the points so obtained. For all practical purposes this is unnecessary; unless the assumed position is greatly in error (say 50 miles or more), the bearing plotted at the meridian nearest the assumed position so nearly coincides with the radio line of position that they may be considered identical. If the assumed position is proved to be greatly in error when a preliminary fix is obtained, entirely satisfactory results may be had by a second plotting of the bearing, as already described.

On a Mercator chart the plotting of a radio line of position is only a little more complicated. The correction angle for converting the observed

bearing to a rhumb line bearing must be determined for each meridian, and the adjusted bearings plotted at the corresponding meridians. A curved line through the points from which the bearing might have been observed on the successive meridians is the radio line of position.

PRACTICAL HINTS

In all forms of navigation it is desirable to do as much as possible of the plotting before taking off. Charts may be prepared for convenient radio navigation by plotting, in advance, bearings to each radio station which might be used in flight. Bearings extending well across the flight area should be plotted at intervals of 10°, using a different colored pencil for each station in order to avoid confusion. With the chart prepared in this way, any bearings observed in flight may be applied to the chart by inspection.

A fix may be obtained graphically, when the ground speed is known, by plotting two bearings on one radio station. Each of the two plotted
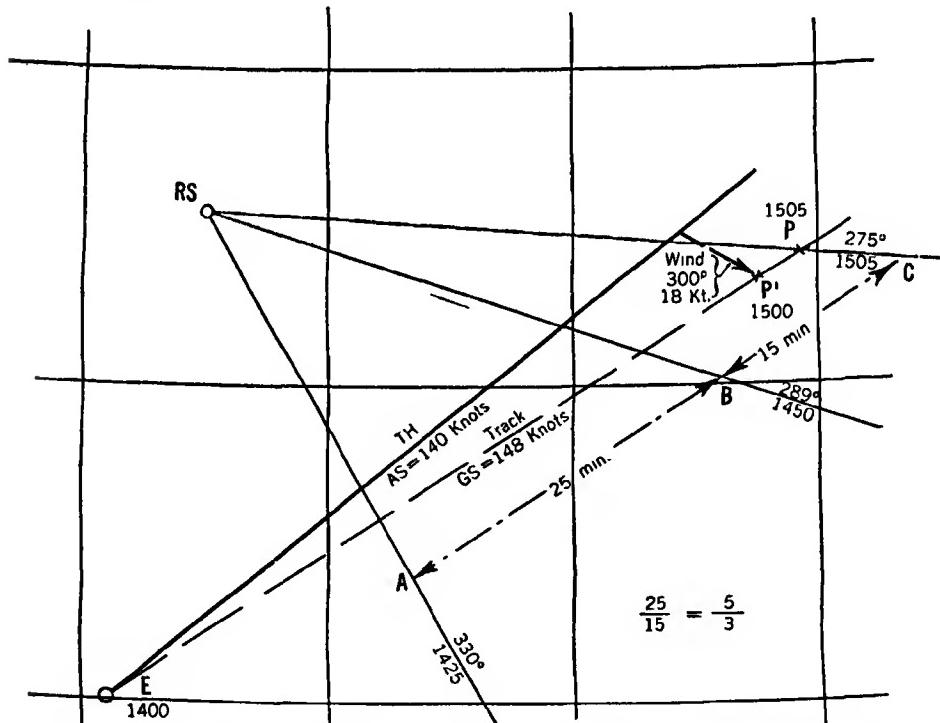
Figure 166. Determination of track, ground speed, and wind, from three radio bearings and time of each.

bearings will constitute a side of a triangle; the third side of the triangle is a line representing the track and distance made good in the time between taking the two bearings. By marking along the edge of a piece of paper the distance made good, at the scale of the chart, and moving the paper toward or away from the station while keeping the edge of the paper

parallel with the track made good, a position is quickly found where the distance made good is exactly included between the lines representing the two bearings. The intersection of the second bearing with the edge of the piece of paper is the fix desired.

In order to be of practical accuracy, the distance run between the two bearings must be great enough that the difference between the two bearings will be at least 10°.

The same principle may also be used to determine track and ground speed, with wind direction and velocity, from three or more bearings and the time intervals between them. The procedure is illustrated in figure 166.

Starting from airport E at 1400, an aircraft is flown along the true heading TH, at an air speed of 140 knots. At 1425 the bearing of the radio station RS was observed as 330°; at 1450 the bearing of the same station was 289°, and at 1505 it was 275°. These bearings were plotted from the meridian nearest the dead reckoning position in each case, with the results as shown in the figure. The time between the first two bearings was 25 minutes, and between the next two, 15 minutes. Reducing these to lowest terms, they are in the proportion of 5 minutes and 3 minutes. Any convenient scale is now laid across the three bearings, moved toward or away from the station and rotated right or left, until a position is found such that 5 units of the scale lie between the first two bearings and 3 of the same units between the next two. The resulting position of the scale in this case is indicated by the line ABC in the figure, and no other position of the scale will do. A line from E parallel to ABC represents the track of the aircraft. The point P′, at proportionate distance between E (1400) and P (1505), represents the point reached in 1 hour, and EP represents the track and ground speed. Knowing the true heading and air speed, the wind direction and velocity are easily plotted and measured as 300° and 18 knots.

At sea, considerable use is made of the principle of "doubling the angle on the bow" in order to determine position from two bearings taken on a visible landmark on the shore. The same principle may be adapted to radio bearings. The procedure is shown in figure 167.
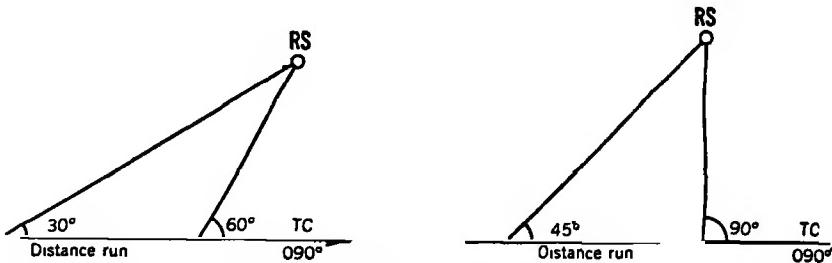
Figure 167 —Position by two bearings on one radio station.

For this purpose "relative bearings" are most convenient—that is, bearings to the right or left of the airplane's head. When the ground speed is known, if a bearing is observed and the same heading is maintained until *double* the original bearing is observed, the distance from the radio

station will always be equal to the distance run between bearings. From a study of figure 167, it should be clear that this is always true, regardless of the magnitude of the two bearings; as long as the second bearing is double the first, an isoceles triangle must result, and the two sides of the triangle will always be equal. It is only necessary, of course, to plot the second bearing, and to lay off along it the distance made good between the two bearings. The point so determined is the position of the airplane at the time the second bearing was determined.

Other combinations of bearings can be used just as satisfactorily, but the computations required are a little more involved. The following table makes it easy to use almost any pair of bearings. The distance run between bearings in each case is to be multiplied by the factor tabulated, in order to find the distance from the station at the time when the second bearing is observed. For practical navigation the factor may be taken from the table to the nearest tenth.

TABLE 6.—*Factors for determining distance from a radio station, by distance run between two bearings*

INITIAL BEARING	SECOND BEARING												
	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°
20°	1.97	1.00	0.68	0.53	0.45	0.39	0.36	0.35	0.34	0.35	0.36	0.39	0.45
30°		2.88	1.46	1.00	0.78	0.65	0.58	0.53	0.51	0 50	0.51	0.53	0.58
40°			3.70	1.88	1 29	1.00	0.84	0.74	0.68	0.65	0 64	0.65	0.68
50°				4.41	2.24	1.53	1.19	1.00	0.88	0.82	0 78	0.77	0.78
60°					4 99	2.53	1.73	1.35	1.13	1.00	0.92	0.88	0.87
70°						5 41	2.75	1.88	1.46	1.23	1 09	1.00	0.95
80°							5 67	2.88	1 97	1.53	1.29	1.14	1.05
90°								5 76	2.92	2.00	1.56	1 31	1.15
100°									5 67	2.88	1.97	1.53	1.29
110°										5.41	2.75	1.88	1.46
120°											4 99	2.53	1.73
130°												4.41	2.24
140°													3.70

INSTRUMENT APPROACH

Experimental work on instrument approach and landing systems has been definitely under way since 1928. A number of systems have been developed, differing chiefly in minor details. While the various systems must be regarded as still in process of development, at the present time (1945) the Civil Aeronautics Administration, in cooperation with the War

Department, is installing at approximately 100 airports equipment similar to that made available at Indianapolis, for service tests, in 1940.

The Indianapolis system is illustrated in figures 168 and 169. The figures and the following text describing them have been adapted from articles in the CIVIL AERONAUTICS JOURNAL for April 1, 1940, and for March 15, 1944.
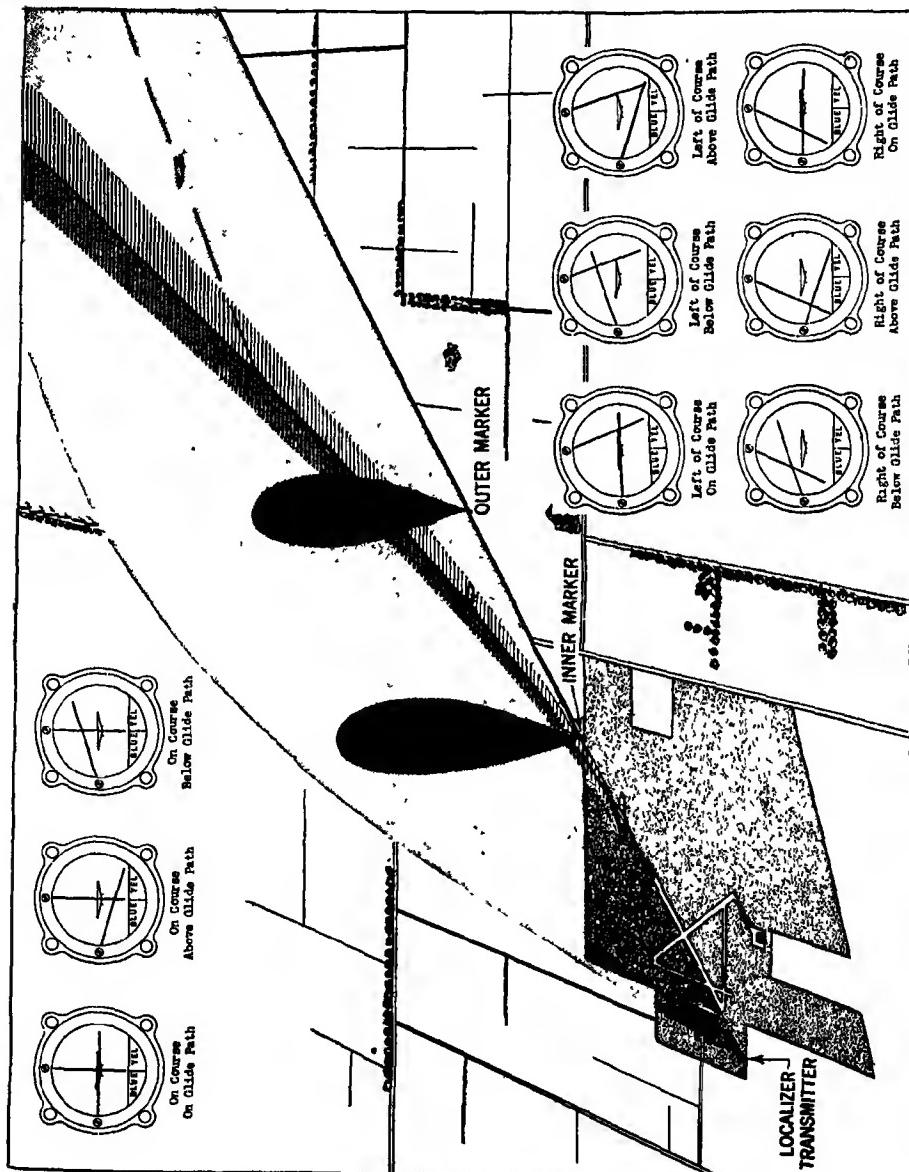
Figure 168.—Indianapolis instrument landing system.

The system consists of four fundamental elements: A runway localizer which provides a range course, or beam, for lateral guidance; a glide path which provides vertical guidance, enabling the pilot to main-

tain the proper rate of descent; and two vertical marker beacons to indicate the progress of approach to the landing field, permitting pilots also to verify their altitudes at these points.

The effect of the localizer beam radio transmission is to provide an imaginary vertical plane extending along the centerline of the runway in the direction of approach. (See fig. 168.) A needle on an instrument before the pilot remains in a vertical position as long as the airplane is in this imaginary plane. If the airplane deviates to the right, the needle swings to the left and the pilot must turn his craft to the left until the needle swings back to the vertical. Exactly the opposite occurs if the aircraft deviates to the left.

The effect of the glide path radio transmission is to provide a surface [10] inclining away from the approach end of the runway at an angle of 3° to 4° from the earth's surface. At about 5 miles from the end of the runway the glide path is approximately 1,500 feet above the ground. (See fig. 169.) A horizontal pointer, crossing the vertical needle mentioned previously, tells the pilot whether the aircraft is flying above or below, or directly along the imaginary inclined surface. If the needle falls below the horizontal the pilot must descend to intercept the glide path and, conversely, if the needle swings above the horizontal the pilot must climb to regain the glide path. (See fig. 168, insets showing instrument readings.)

The intersection of these two imaginary surfaces provides an imaginary line (see black line followed by aircraft in fig. 168) which inclines at a gentle angle upward from the end of the runway for many miles. By means of the two instrument indications already described the pilot can fly his aircraft downward along this imaginary line with a high degree of precision.

The signals of the radio markers are directed upward and fill a fan-shaped space intersecting the localizer beam and crossing the glide path. (See fig. 168.) The outer marker is about 2 miles from the airport and intercepts the glide path at a point where it is 510 feet from the ground. The inner marker is located at the boundary of the field in line with the runway and intercepts the glide path at an altitude of 45 feet. The exact distances are shown in figure 169.

Flying over the outer marker causes a purple light to flash on the aircraft's instrument panel at a rate of two dashes per second for a period of 8 seconds, while at the same time a characteristic audible signal is received by the pilot through his headphones. The inner marker flashes an amber light at a rate of six dots per second for approximately 1½ seconds, and provides an audible signal plainly distinguishable from that of the outer marker.

At the bottom of the instrument faces shown in figure 168 there is a sector split in the middle with blue on the left and yellow on the right. The chart used by the pilot is tinted yellow in the area to the left of the localizer

[10] Actually, the glide path is formed by a portion of a curved surface. but, the portion utilized for the approach is relatively straight. and for the purpose of a simplified explanation may be thought of as a narrow inclined surface, curved slightly at the bottom to meet the runway at a gentle angle.

beam and blue to the right, as indicated in figure 169. Thus, whenever the
vertical needle points to the blue sector the pilot knows he is in the blue
area indicated on the chart, and if the needle points to the yellow sector
he can be sure he is in the yellow area of the chart, regardless of the head-
ing of the ship.

Four complete sets of equipment are installed at Indianapolis, provid-
ing instrument landing facilities for four wind directions. The whole
system is monitored and controlled from the airport control tower, per-
mitting a ready choice of the proper runway suitable for use under existing
wind conditions at the time of landing.

The procedure employed by the pilot to approach and intercept the
glide path is clearly shown by the arrows and explanatory comment in
figure 169.
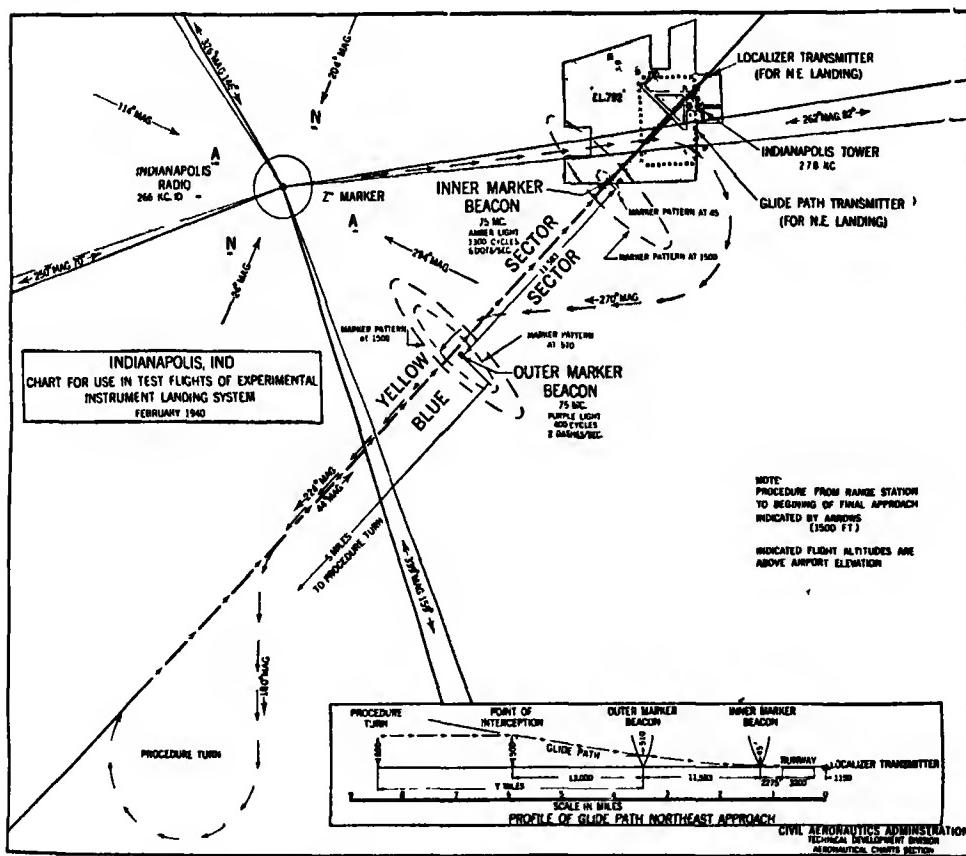
Figure 169.—Chart used in test flights of Indianapolis instrument landing system.

A set of controlled approach lights is operated in conjunction with the
instrument landing system at Indianapolis. This system has three possible
applications: It can be used independently of radio aids to assist in con-
tact landings at night or under conditions of restricted visibility; it can be
used in conjunction with the conventional directional radio range whereby

the approach would be made on instruments and the landing by contact; and, thirdly, it can be used to supplement an instrument landing system.

In the latter case, an instrument landing approach is made in the manner previously described and the first steps of an instrument landing followed, but upon passing the inner marker the pilot picks up the approach lights as soon as they become visible. The pilot is thereby provided with visual aids for making actual contact with the runway.

The first 1,200 feet of approach lights are equally spaced at 200-foot intervals on each side of the approach. The remaining 1,300 feet of approach lights are spaced at 100-foot intervals. Flush-type runway lights then continue along either side of the runway proper.

Usually, no glide path is included in the systems now being installed, for equipment is not available, but the equipment is expected to be installed as soon as it is available. Current installations include three marker beacons, instead of the two described.

Use of the localizer and markers alone permits instrument approaches under weather conditions much less favorable than the present minimums. Approaches to an airport with 100-foot ceiling and one-fourth mile visibility will become feasible, whereas present minimums are 400-foot ceiling and 1-mile visibility.

LINEAR APPROACH LIGHTS

As a further visual aid in making landings under conditions of restricted visibility, there has been installed along the southwest approach to the southwest-northeast runway at Indianapolis a row of 15 linear approach lights spaced at 100-foot intervals, commencing 3,100 feet from the end of the paved runway, approximately 800 feet before reaching the inner marker, and extending toward the runway.

These lights consist of horizontal neon bars, each 6 feet 6 inches long, mounted approximately 4 feet above ground. They are brilliantly lighted with the characteristic neon red color and are focused toward the incoming aircraft.

It need scarcely be pointed out that with the general installation of a satisfactory system for instrument approach and landings, both on the ground and in the aircraft, and with pilots proficient in its use, the last essential for a complete system of safe, all-weather air transportation is provided

RADIO OPERATOR'S PERMIT

In order to operate 2-way radio, a pilot is required to hold at least a third class radiotelephone operator's permit, issued by the Federal Communications Commission. The examination for this permit consists of 10 questions, as follows:

> Three on the Communications Act of 1934.
> Two on the International General Radio Regulations (Cairo Revision).

Five on the Rules and Regulations of the Federal Communications Commission.

The 10 questions which make up any given examination are selected from those in the "Study Guide and Reference Material for Commercial Radio Operator Examinations," published by the Federal Communications Commission. The pamphlet may be obtained from the Superintendent of Documents, Washington, D. C., for 15 cents. Additional information may also be obtained from any local inspector of the Federal Communications Commission.

EXAMPLES

Example 1.—While flying the radio range course between The Dalles, Oregon, and Ellensburg, Washington (see plate III), in thick weather, a pilot wished to verify his position along the course. By means of radio direction finder he determined the true bearing of the Pendleton radio range station as 118°

Required.—The position of the airplane.

The pilot supposed himself to be somewhere near Yakima; consequently, the bearing was plotted with the meridian passing through Yakima, at latitude 46°30'. This line passed well to the north of Pendleton, so a second line was drawn, from the Pendleton range station and parallel to the first line. The intersection of the second line with the northeasterly course of The Dalles radio range station marks the position of the airplane, about 3 miles south of Harrah.

Instead of drawing the two lines, as just described, some prefer to adjust the protractor to the desired angle, then slide it along the meridian until the protractor arm passes through the point in question. The bearing may then be drawn directly from the station.

If the Seattle sectional chart were being used on this flight, it would be easier to plot the bearing directly from the Pendleton radio range station on the La Grande chart, transferring the bearing to the Spokane chart, and in turn to the Seattle chart, where it crosses the boundaries between the charts. The bearing to be plotted from the Pendleton station is obtained as follows (see p. 226) :

> 118° bearing observed at airplane.
> +180°
> 298° reciprocal bearing.

The difference of longitude between the airplane and the radio range station is not quite 2°. Multiplying this number by the convergence of 0°6 per degree of longitude (see p. 47), we obtain $2 \times 0°6 = 1°2$, or, to the nearest whole degree, 1°. The correction is to be added, since the airplane is west of the station.

> 298° reciprocal bearing.
> +1° correction for convergence.
> 299° bearing to be plotted from Pendleton radio range station.
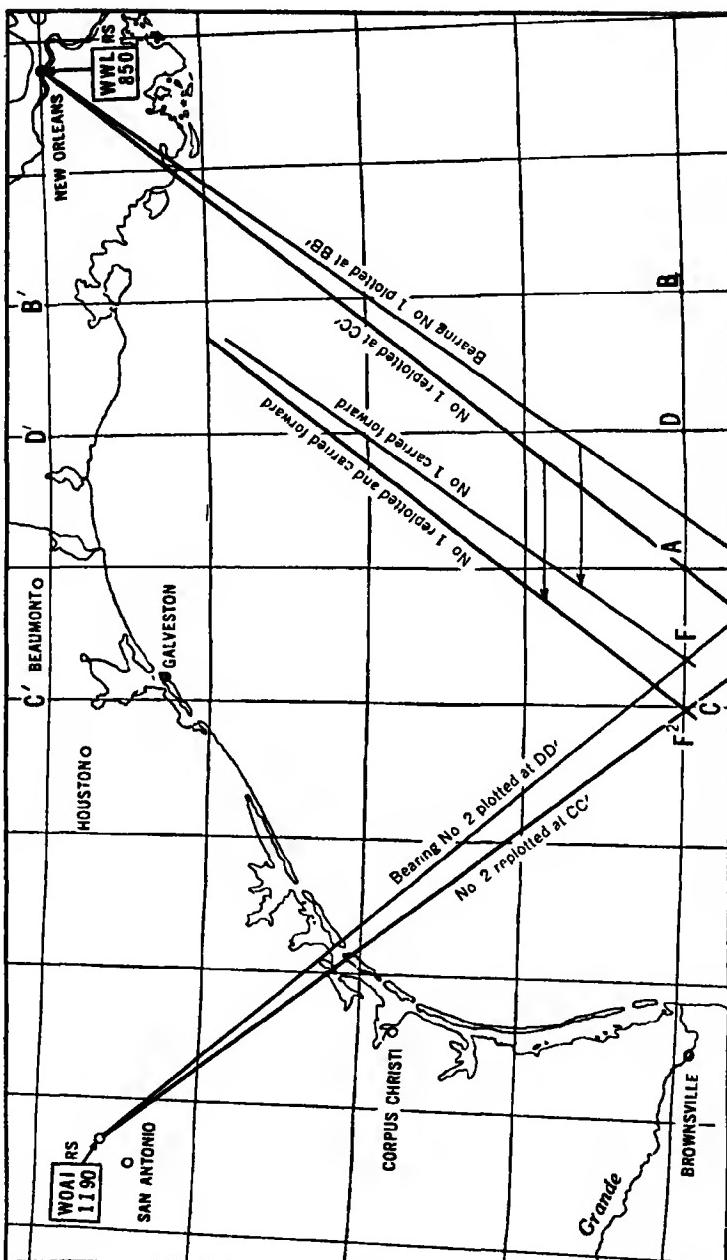
Figure 170.—A fix from radio bearings when the assumed position is considerably in error.

The added work of obtaining the bearing to be plotted from the station, and the inconvenience of transferring the bearing from one chart to another (or even to a third chart, as in this example), well illustrates the need for, and the convenience of, the smaller scale charts for plotting radio bearings.

Example 2.—In the preceding example, if the Pendleton radio range station had been equipped with the necessary apparatus (as are the naval radio direction finder stations along our coasts), the pilot might have called Pendleton and requested that his bearing from that station be determined. When the bearing was reported back by radio, he could have plotted the bearing at once with the meridian nearest the radio station (not with the meridian nearest the location of the airplane), and its intersection with The Dalles radio range course would have determined his position as in example 1.

Example 3.—On a direct flight from Key West, Fla., to Brownsville, Tex., a pilot was approximately at position *A*, figure 170, but by dead reckoning believed himself to be in the vicinity of *B*. By radio direction finder he determined the bearing of WWL (New Orleans) as 039°, which was plotted on the chart with the meridian nearest *B*, affording "bearing No. 1." Not until 30 minutes later was he able to obtain the bearing of WOAI (San Antonio). Since he was flying due west at an estimated ground speed of 125 mph, his true position was now at *C*, although he believed himself to be near *D*. The bearing of WOAI, 320° true, was therefore plotted at the meridian of *D*, resulting in "bearing No. 2." Carrying bearing No. 1 due west 62.5 miles (the dead-reckoning distance and direction made good between the taking of the two bearings), fixes the approximate position of the airplane at *F*.

Since this fix is nearly 2° of longitude away from the supposed position at *D*, it is decided to replot both bearings, plotting them at the meridian nearest the preliminary fix. Bearing No. 2 is replotted, and No. 1 is replotted and carried forward as shown, giving the fix at F_2. From F_2 an adjusted course to Brownsville can be determined, and the estimated time of arrival is revised, not only to allow for the shorter distance ahead, but also for the tail winds which had placed the airplane so much farther ahead than was supposed.

Example 4.—A pilot was flying a compass heading of 347° in the vicinity of *P* (fig. 171) when he obtained the relative bearing of the radio station *RS*, 60° to the right of the airplane's head. Compass deviation on this heading, 2° W.

Required.—The line of position on the radio direction finding chart of the region.

To rectify for deviation of the compass (Case II, p. 118), subtract ᵥesterly deviation: 347° — 2° = 345°, the magnetic heading of the airᵥlane. Since the observed bearing was to the right of the airplane's head, ᵥ must be added: 345° + 60° = 405°, which is 45° past 360° (405° — 60° = 045°). The bearing of the station is 045° magnetic.

From the radio station draw a straight line through the 45° graduation of the compass rose as read from the outer figures; this is the desired line of position, at some point on which the airplane was located when the bearing was observed.

Example 5.—In the preceding example it is desired to obtain greater precision by applying corrections for convergence and for the difference in variation between the position of the airplane and the radio station.

Since the airplane is approximately 2° of longitude west of the radio station, the correction for convergence is $2 \times 0°6 = 1°2$, which is to be
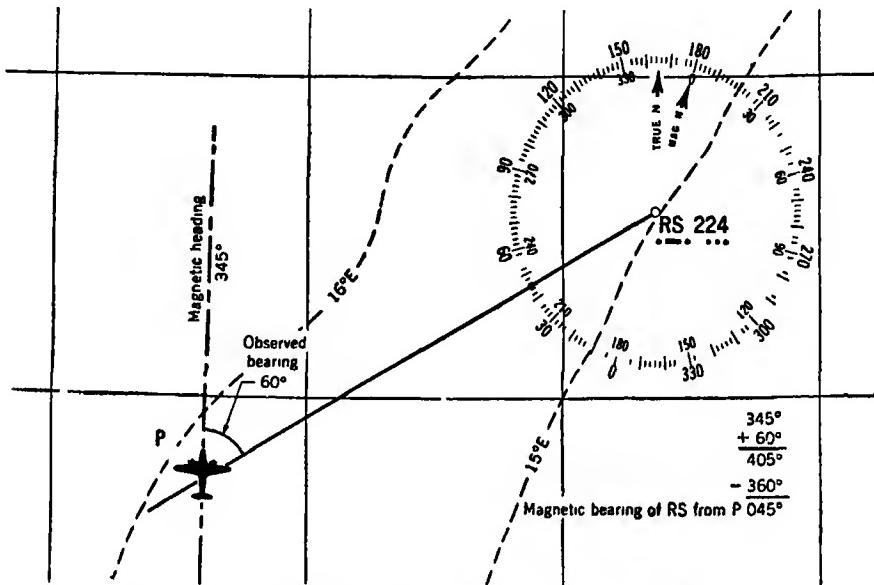
Figure 171. Plotting a radio bearing on a radio direction finding chart.

added. The difference in magnetic variation is 1°, which is also to be added (add "when easterly variation decreases toward the station," p. —). To the nearest degree, then, the correct bearing is obtained as shown in the lower right corner of figure 172, and plotted as shown by the light broken line in the figure.

Example 6.—Instead of measuring the relative bearing from the magnetic heading in example 4, it is assumed that deviation and variation were set off as on the more recent direction finders, and that the true bearing of the station was read directly as 061°.

For precise results, without the necessity for applying any corrections, a protractor of the type illustrated in figures 80 and 160 is adjusted to read 061°, at the meridian nearest the position of the airplane, and moved along the meridian until the protractor arm passes through the station. A line drawn along the edge of the protractor is the desired line of position.

Example 7.—A flight is to be made from the municipal airport, Houston, Texas, to the municipal airport at Shreveport, Louisiana. Plate II, the radio direction finding chart of the area, has been overprinted

with the plotting required prior to the flight, and shows the true course, the check points selected and the distances between them, and true radio bearings from the check points to selected radio stations.

From the weather data it is decided that the flight is to be made at 6,000 feet, the wind at that altitude being 250° and 22 mph. The true air speed under predicted conditions is 135 mph, which should result in a ground speed of 150 mph. From the rate of climb and of descent, both of which are 500 feet per minute, the time spent in climbing and in descending is determined as 12 minutes and 21 miles covered over the
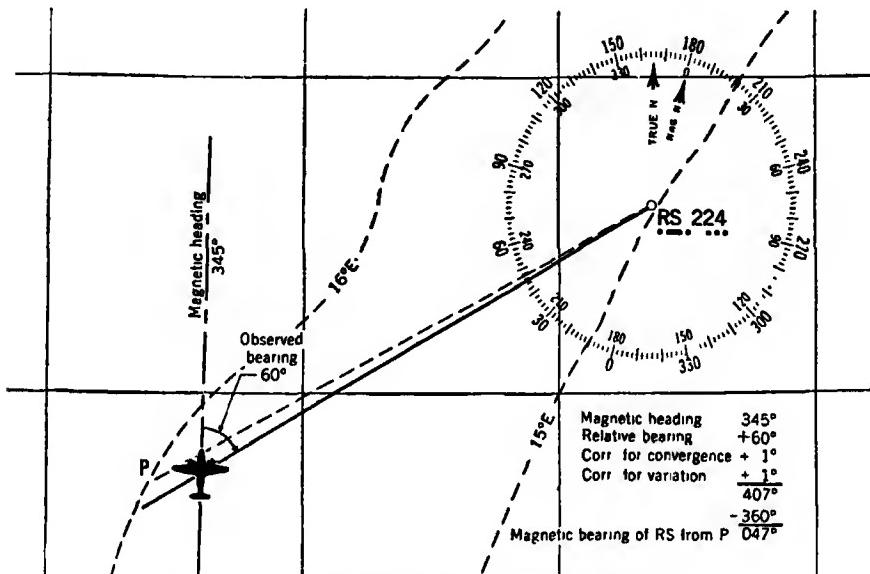
Figure 172.- Bearing   direction finding chart corrected for converge

ground, in each case. The ground speed during climb and descent is only 105 mph, based on the mean wind between the airport elevations and flight level.

Complete data for the flight are shown on the chart and in the following table.

On the first half of the flight the track is checked by bearings taken on the Houston range station, differing only slightly from the reciprocal of the plotted course (204°). On the second half of the flight the track is checked by bearings on the Shreveport range.

The first check point is reached, and the plotted bearings verified within about a degree, which is as close as may be expected. The time was 27 minutes, instead of the estimated 28 minutes, but no change in the other data was made in view of the possible error in position on a small scale chart, and other possible inaccuracies in wind and flight data.

Check point 2 was reached in 46 minutes, instead of the estimated 47 minutes, so that the elapsed time between these points agreed with the estimate. Check points 3 and 4 were reached 1 minute behind the estimated times, and the airplane was landed at Shreveport just 1 minute late.

Data for Flight from Houston to Shreveport

Leg No.	Ck. Pt. No.	From	To	TC	WCA	TH	Var	MH	Dev	CH	Local Distance [1]	Total Distance [2]	GS	Time (Est.)	Climb time & distance	Descent: time & distance	Cruise time & distance	Total time
1		Houston	Shreveport	024°	7°−	017°	8° E	009°	3° +	012°	—	221			0:12 / 21 mi.	0:12 / 21 mi.	1:12 / 179	1:36
	1										62	62 / 159	150	0.28				
	2										46 / 108	108 / 113	150	0:47				
	3										57 / 165	165 / 56	150	1:10				
	4										15 / 180	180 / 41	150	1 16				
			Shreveport								41 / 221	221 / 0	150	1 36				

[1] "Numerator" = distance between check points. "Denominator" = total distance from starting point.

[2] "Numerator" = total distance from start. "Denominator" = distance still to go.

This example illustrates the general use of the radio direction finding charts, when plotting true bearings from the meridian nearest the dead reckoning position. If the true bearings are converted to magnetic bearings and plotted from the various stations by means of the magnetic roses printed around the stations, the error involved in that method may be seen. The direction finding charts should in all cases be supplemented by larger scale charts, such as the sectional charts, terminal charts, or airport charts.

QUESTIONS

1. Name the most important functions of aeronautical radio.

2. In what way is radio of importance to the light-plane owner?

3. What is the principal advantage of the Lambert projection for radio navigation?

4. How are the four courses ("beams") of a radio range station obtained?

5. Are the four beams of a range station always at right angles? Why?

6. How may a pilot know to what radio range station he is listening?

7. Describe two methods of keeping on the beam.

8. How may a pilot be sure that the radio aids to navigation on his chart are up to date?

9. What is meant by an "attention signal"?

10. What is a cone of silence?

11. What is a false cone of silence? How may it be distinguished from a true cone of silence?

12. What is the function of a Z marker beacon?

13. What is meant by multiple courses? Bent courses? Night effect?

14. How may pilots distinguish between a multiple course and a true on-course zone?

15. Of what importance is drift in radio range flying? In orientation procedure?

16. If a pilot located himself as being in one of the *A* quadrants of the Pittsburgh range station, what method of orientation should he follow? What method should be followed in an *N* quadrant of the same station?

17. What is a standard procedure turn?

18. What procedure should be followed in reversing the direction of flight along a beam?

19. When flying the radio ranges, is it necessary to bother with dead reckoning?

20. What is meant by "bracketing a beam'?

21. When MUST a pilot fly to the right of a beam, and when may be fly *in* the beam?

22. What is the minimum time for determining, from the fading or building-up of signal strength, whether flight is toward or away from a station?

23. Is it ever possible to fly away from a station and have the signal strength increase?

24. What checks might a pilot make to assure the accuracy of a beam identification?

25. What information may be obtained from a fan marker beacon?

26. What is meant by a radio fix? A range approach channel?

27. Distinguish between a radio compass, a radio direction finder, and an automatic direction finder.

28. Are the indications of a radio direction finder subject to more or less error than a radio beam?

29. Is orientation ever necessary when using a radio compass?

30. What is meant by a radio line of position?

31. What is a running fix?

32. What errors are involved in plotting from a radio station the reciprocal of a bearing observed aboard an aircraft?

33. What is the principal disadvantage of the Mercator projection for radio navigation?

34. What is meant by a relative bearing?

35. How may wind be determined by means of the radio compass or direction finder?

36. What advantages are offered by the new very-high-frequency radio range stations?

37. Give a general description of the four elements of the Indianapolis instrument approach and landing system.

PROBLEMS

1. The true bearings of the beams of a radio range station are 15°, 80°, 160°, and 260°. Sketch the four beams and mark the A and N quadrants.

2. Assume that the station of problem 1 is located in Canada, and mark the A and N quadrants.

3. Determine the average bisectors of the quadrants of the station of problem 1.

4. From the following data obtain the true bearing in each case; the letters L or R after the relative bearing indicate that the station is toward the left, or right, respectively:

	1	2	3	4	5
Compass heading	20°	350°	240°	160°	160°
Deviation	2° E.	3° W.	5° E.	2° W.	2° E.
Variation	4° E.	8° W.	13° E.	6° E.	6° W.
Relative bearing	28° L.	40° L.	110° R.	35° R.	35° L.
True bearing					

5. From the following data, obtain in each case the bearing to be plotted from the magnetic compass rose of an aeronautical chart for radio direction finding. The letters L or R after the relative bearing indicate that the station is toward the left, or right, respectively. No corrections need be applied for convergence or for difference in variation.

	1	2	3	4	5
Compass heading	35°.	270°.	315°	330°...	170°.
Deviation	4° W	2° E..	3° W.	7° E......	5° W.
Relative bearing	35° L	95° R..	175° R	40° R.	38° L.
Magnetic bearing					

6. Referring to figure 154, suppose that an A signal is received from station 1, an N signal from station 2, and an A signal from station 3: what is the position of the airplane?

7. Example 7 describes the use of a radio direction finding chart for a flight from Houston to Shreveport, based on plate II. Using the same chart, assume that the flight is to be continued from Shreveport to Dallas and back to Houston, and tabulate the data required.

8. A pilot in flight obtained true bearings on three radio range stations, as follows:

Shreveport 062°.
Dallas 311°.
Navasota 198°.

Using plate II, determine the position of the airplane.

9. Using a radio compass a radio station is tuned in, but it is uncertain whether the station is directly ahead of, or directly behind the aircraft. A 90° turn to the right is made and the new heading maintained for 10 minutes, after which a left turn of 95° is required to head the aircraft directly toward the station. Is the station ahead of or behind the aircraft?

10. On an aircraft headed east, the true bearing of a radio station is determined as 175° or 355°. After flying east for 10 more minutes at 140 mph, the bearing is determined again as 185° or 005°. Which of the last two bearings is correct, and what is the distance from the station?

11. While flying the southeast beam of the Waco radio range (plate II), the bearing of the Austin range station was observed as 232° true. What was the position of the airplane?

12. The position of the airplane in the preceding example was reached just 30 minutes after passing the Waco cone of silence. The compass heading in the meantime had been 135°; deviation as in figure 54; true air speed 120 mph. What was the wind direction and velocity?

Chapter X.—CELESTIAL NAVIGATION

PRACTICAL VALUE

Celestial navigation is the art of determining position on the earth from observations of celestial bodies (the sun, moon, stars, and planets).

In time of peace, celestial navigation with present methods and equipment will seldom prove of practical importance for flights of less than 1,000 miles. For such distances, its chief value is that of a fascinating hobby which may some day prove of value, since the combined use of piloting, dead reckoning, and radio should ordinarily afford satisfactory results.

With the development of large transports capable of flying great distances nonstop, longer and longer flights have been included in air-transportation schedules. Even before the war, regular flights across both the Atlantic and the Pacific had become commonplace. Under the impetus of war, not only have our transport lines spanned nearly the whole earth, but our bombers have made mass flights deep into enemy territory, where radio was not available. For flights such as these celestial navigation is not only practical, but necessary.

For the future, the transoceanic routes, like the airways within the United States, will be equipped with the most advanced radio facilities. There are those who believe that radio will always provide the leading navigational method in air transportation, and probably they are right. For communications it is a necessity, and for easy position finding it is unexcelled; however, it is always possible that failure may occur, either in transmission or reception, and celestial navigation should be practiced in order to assure proficiency in such emergencies, if for no other reason.

Efficient operation demands that long flights be made at high altitudes, and a large percentage of such flights would be above any overcast. This would prevent the direct determination of drift and ground speed, and would make dead reckoning of doubtful value; it would not affect radio, except in the event of complete failure or excessive static, and it would not affect celestial navigation. For longer flights, then, especially over ocean routes and for many military missions, celestial navigation becomes a primary method, and of at least equal importance with radio.

ACCURACY

The accuracy of the results depends on the skill of the observer, the instrumental equipment, and the conditions under which the sextant observations are taken. By means of astronomical observations a surveyor on the stable earth can determine his geographic position within a few yards; on a ship at sea, position can usually be determined within a mile or two. Under average conditions in the air, an accuracy of 5 to 10 miles should ordinarily be obtained, although considerably greater errors may occur with a light airplane and bumpy air.

Since a single observation may be greatly in error, it is common practice to take from 5 to 10 observations in quick succession, and to determine the line of position from the average of the observations. Obviously, the better the flying conditions the smaller the number of observations needed for a satisfactory determination.

SIMPLICITY

There is a widespread belief that celestial navigation is very difficult, and can be used only by expert observers and mathematicians. On the contrary the method is very simple. In the practice of celestial navigation the most difficult part of the whole process is the taking of the sextant observation; obviously, this is largely a matter of mechanical practice.

Aside from the observation with a sextant, three other steps are necessary. The first is to note the exact time of the observation; the second is to compute the line of position from the sextant observation and the time it was made; and the third is to plot the line of position on the chart. An error of 4 seconds in noting the time of observation will produce a maximum error of only 1 mile in the line of position; the computations have been reduced to simple arithmetic, requiring nothing more than addition and subtraction; and the plotting of the position line on the chart is as simple as measuring the course angle.

In addition to the instruments ordinarily used in other methods of navigation, the following equipment is required: sextant, chronometer (accurate watch), the current Air Almanac, and the preferred tables for performing the necessary computations. A suitable form for computing the line of position is convenient, but is not absolutely necessary.

BASIC PRINCIPLES

Almost directly above the north pole of the earth there is a fairly bright star known to most people as the North Star. It is also called the Pole Star, or, more properly, Polaris. Let us suppose that this star were *exactly* over the north pole: To an observer at that point it would appear to be directly overhead; that is, its altitude (angle of elevation above the horizon) would be 90°.

To an observer at the equator the star would appear to be on the horizon, with an altitude of 0°. The star is actually in line with the earth's axis, nearly 4,000 miles beneath his feet, but the distance to the star is so great by comparison that all rays from the star to different points on the earth appear to be parallel. Thus (fig. 173), from *all* points on the equator the altitude of the star is 0°, and the equator may be called a "circle of position," passing through all points where the altitude of 0° might be observed.

To an observer at *A*, latitude 30°, the line *BC* will appear to be horizontal, and he will see the star one-third of the way from the horizon to the point in the heavens directly overhead (the zenith)—that is, the altitude will be 30° (the same as the latitude). As before, it is un-

important what point on the 30th parallel is considered, since all rays from the star are parallel, and the altitude of the star is 30° from *all* points on the parallel, and from no other point. The 30th parallel may therefore be called a circle of position, or a "circle of equal altitude," passing through all points where the altitude of the star is 30°. In the same way it can be shown that the 40th parallel is a circle of position for all points where the altitude of the star is 40°, and so on.
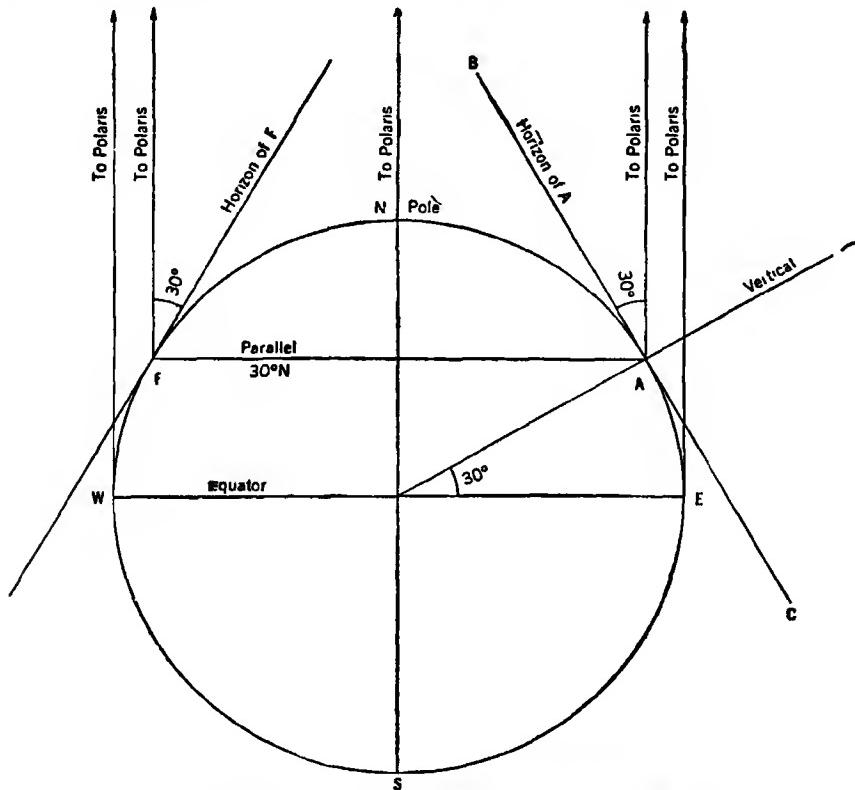
Figure 173 Parallels of latitude as circles of position.

Figure 174 is an ordinary polar equidistant projection of the northern hemisphere, with our fictitious star projected down upon the pole, the point directly beneath it on the earth. The parallels of latitude, at 10° intervals, represent so many circles of position drawn about the point directly beneath the star (the "sub-stellar point") as a center. Since the scale is true along all meridians of this projection, it is clear that the radius of the 60th parallel is equal to 30° of latitude, its actual distance from the pole. Similarly, the radius of the 30th parallel, where the observed altitude would be 30°, is equal to 60°, and in each case the radius is equal to 90° minus the altitude that would be observed.

These principles hold true not only for a star directly over the pole, but for all stars. Every star is the center of a system of concentric circles of position which moves with the star in its daily passage over the earth.

By reference to the Air Almanac the point directly beneath a star may be known for any instant of time, and any given circle of position may be drawn around that point with radius equal to 90° minus the observed altitude.

We do not usually think of distances in terms of degrees and minutes, although we are accustomed to measuring distances along a meridian (latitude) in these terms. When great-circle distances are computed
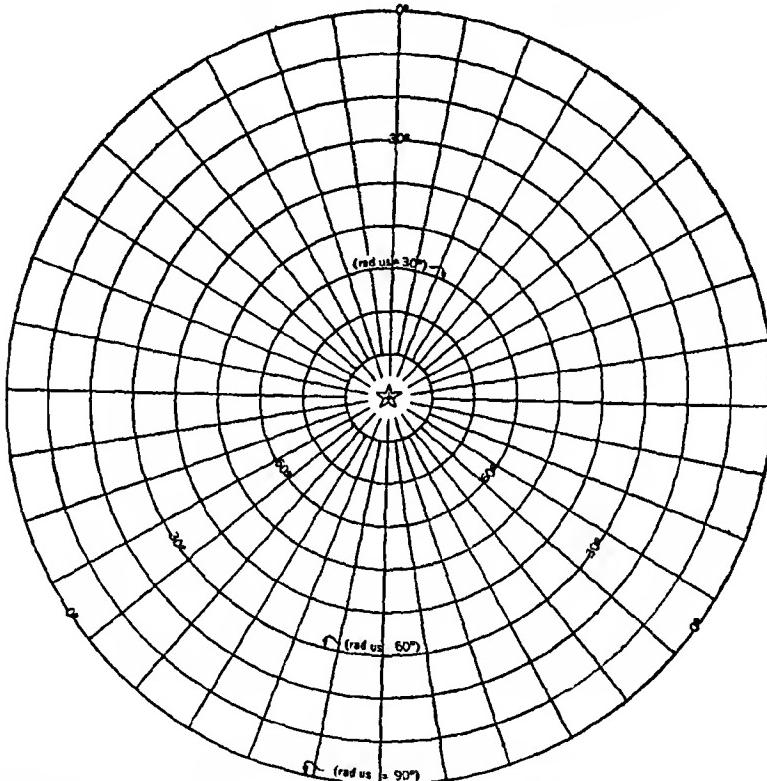
Figure 174.—The radius of a circle of position is equal to 90° minus the observed altitude.

between any two points, regardless of the direction, they are always computed in degrees and minutes, and then converted into the desired conventional units, such as nautical miles, statute miles, or meters.

A chart may have a scale of distances in terms of degrees and minutes of a great circle, just as it has a scale of distances in terms of statute or nautical miles. If a small scale chart (the scale of the planning charts, or smaller) were provided with such a scale, it would be possible to plot on the chart, from the Air Almanac, the position beneath any star at the instant of observation; and with that point as a center, to draw the circle of position graphically, with a radius equal to 90° minus the observed altitude, with no computations whatever. This principle may prove of very practical value on special charts of the transoceanic routes, or even some of the transcontinental routes. It has already been used

by the Army Air Forces for several experimental charts at a scale of
1:10,000,000.

We have seen that the observed altitude of a star definitely deter-
mines a circle of position at a known distance from the point beneath the
star. If at the same time and place the altitude of a second star is ob-
served, a second circle of position is determined; since the observer is on
both circles, he must be at a point where the two intersect. This is
illustrated in figure 175, which is a greatly reduced representation of the
planning chart of the United States. The positions of the stars observed
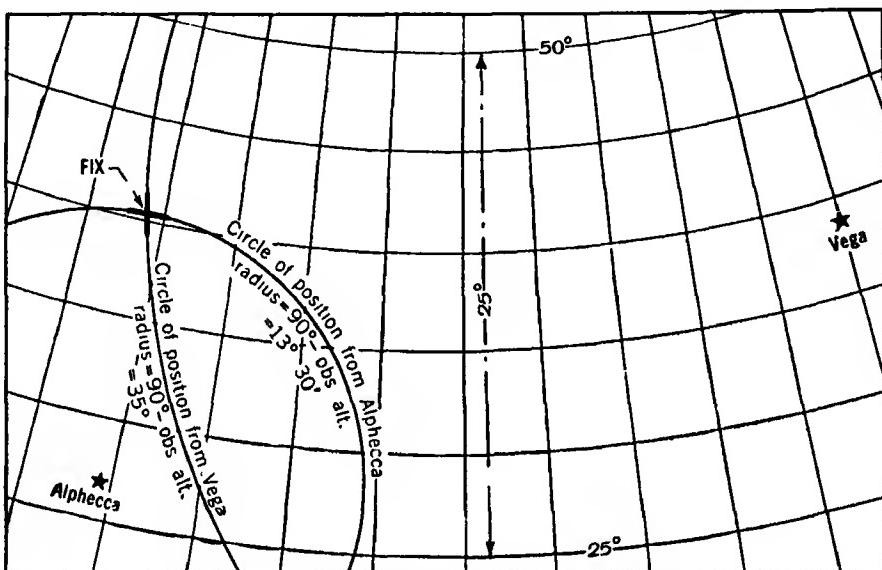
Figure 175.—Two circles of position establish location.

(Vega and Alphecca) at the moment of observation were plotted on the
chart from data in the Almanac; then with radius equal to 90° minus the
observed altitude in each case, the two circles of position were drawn,
determining the fix as shown. Note that the distance between the top and
bottom parallels of the chart is 25°, the lengths of the radii being laid off
proportionately at the same scale.

From the figure it may be seen that the two circles of position would
also intersect just outside the southern border of the chart. For every
pair of intersecting circles there must be two points of intersection, but
this is not confusing in practice, since the two points are usually far
enough apart that one of them may be dismissed as impossible. In the
problem illustrated, the poorest navigator, somewhere in Nevada, should
be able to know at once that he was not in Mexico, 1,500 miles away.
When using larger scale charts for this purpose, the radius of the circle
of position is often too long for the limits of the chart and the circle of
position cannot be drawn as just described; the procedure must therefore
be slightly modified.

THE LINE OF POSITION

To determine a circle of position on the larger scale **charts, the navi-**
gator starts with an assumed position, *A*, figure 176, which may be either
his dead reckoning position, a nearby projection intersection, or any posi-
tion arbitrarily assumed for most convenient use with the tables selected.
Using the preferred tables, he then computes the azimuth and the altitude
of the star as it would have been observed from the assumed position at
the instant of observation. Let us suppose that the computed azimuth of
the star is 250° and the computed altitude 36°49′: the line *AZ* is plotted
from *A*, and represents the azimuth of the observed body; in reality it
is the end section of a radius of the circle of position on which the point
A was located at the instant of observation, and the line *LP*, at right
angles thereto, is a short section of that circle. Now suppose that the
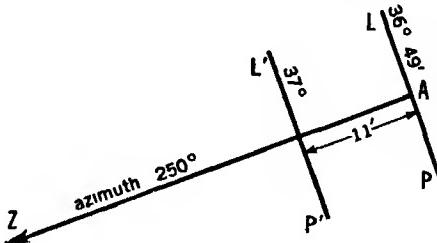
LP = Line of position through assumed position
36° 49′ = Altitude computed for assumed position
37° 00′ = Altitude observed
    11′ = Difference between observed and computed altitudes
    L′P′ = Line of position through true position

Figure 176. The line of position on large scale charts.

altitude actually observed was 37°00′: this is 11′ greater than the altitude
computed for the assumed position and we know, therefore, that the ob-
servation must have been taken at some point on a circle of position 11′
closer to the star than the circle of which *LP* is a part. Therefore, a dis-
tance equal to 11′ of latitude is laid off along *AZ*, toward the star, and the
line *L′P′* (at right angles to *AZ* and parallel to *LP*) is a short section of
the circle of position on which the navigator was located when the observa-
tion was made. In such cases the radius of the circle of position is so
long that the short sections of circumference may be drawn as straight
lines without appreciable error. Such a short section is commonly called
a line of position.

In practice, of course, it is not necessary to draw the line *LP;* the
altitude difference is simply laid off from the assumed or dead reckoning
position along the plotted azimuth, and a line at right angles thereto
through the point so obtained is the desired line of position.

As in the case of a radio line of position (p. 232), a line of position
from a single star does not definitely determine position; it determines
only a line at some point on which the observer was located at the instant

of observation. In order to obtain a fix, lines of position from two or more stars must be obtained; since the observer is somewhere on each line of position, he must be located at their common point of intersection. When three lines of position are plotted they seldom meet in a point, because of inaccuracies of observation; instead, a triangle is formed, and the position may be regarded as anywhere within the triangle. In theory, the most probable position of the observer is often outside the triangle formed by the three lines of position. In air navigation, however, the exact solution of this "triangle of error" is an unnecessary refinement, and for practical purposes the position may be regarded as anywhere within the triangle.

Although one line of position does not provide a fix, it may still prove of real value. For example, if the line is approximately parallel to the path of the airplane, it informs the pilot as to whether or not he is on course; if the line of position is approximately at right angles to the track it furnishes a definite check on the distance made good, and on the ground speed. In the latter case, if the starting point or the destination is used as the assumed position, the distance made good or the distance yet to go is obtained directly, without any additional calculations. A single line of position from celestial observations may be combined with a radio line of position in order to obtain a fix; or, if a pilot has been able to determine his position as somewhere along a fairly straight section of river, shore line, or other landmark, a single position line crossing the feature would provide a fix.

In celestial navigation, as in other methods, the projection of the chart is of no little importance. When the difference between the observed and computed altitudes is comparatively large, as is frequently the case in the air, additional error is introduced by the use of unsuitable projections. Due to the accuracy of the Lambert projection in representing azimuths, and the fact that a straight line thereon closely approximates the track of a great circle, error from this source is very small. The properties of the Lambert projection also make it particularly suitable for the graphic method of position finding from celestial observations, as suggested above for small scale charts.

CELESTIAL COORDINATES

As we look at the night sky, it is as though a great bowl were inverted over the earth, and the stars and other heavenly bodies were fixed to its inner surface. This inverted bowl is referred to as the celestial sphere. It has a system of coordinates which correspond closely with those of the terrestrial sphere, although the names are different. The easiest way to become thoroughly familiar with the celestial coordinates is to compare them with the familiar terrestrial terms.

The earth rotates on its axis, the extremities of the axis being known as the north and south poles, respectively. Halfway between the poles, an imaginary plane perpendicular to the axis cuts the surface of the earth in a line known as the equator. The terrestrial axis and equator are

considered as extended to meet the celestial sphere, their intersections therewith being known as the north and south celestial poles and the celestial equator. As the earth rotates daily from west to east on its axis, there results an *apparent* rotation of the celestial sphere from east to west, on the axis passing through the celestial poles.

On the earth, latitude is reckoned from 0° at the equator to 90° north latitude at the north pole and 90° south latitude at the south pole; on the celestial sphere latitude is known as **declination.** The distance
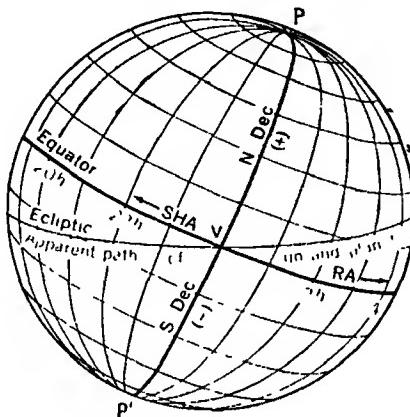
P, P' = the celestial poles

    V   the vernal equinox or "celestial Greenwich"

Declination is measured
      North of the equator (+) or
      South of the equator (−)

Right Ascension is measured from V toward the east
      from 0h up to 24h

Sidereal Hour Angle is measured from V toward the
      west, from 0 up to 360°

Figure 177.—The celestial sphere.

north or south of the celestial equator is known as north or south declination; as with terrestrial latitude, declination is expressed in degrees, minutes, and seconds. North declination is often designated as plus (+), while south declination is known as minus (−).

The longitude of a point on the earth is usually referred to the meridian of Greenwich as a zero point; on the celestial sphere the zero point is known as the vernal equinox, or the first point of Aries. For convenience, this point is usually designated by the symbol ♈, which is suggested by the horns of Aries, the Ram. It is the intersection of the ecliptic (see p. 284) and the celestial equator, and is the point at which the sun appears to cross the equator in the spring, as the earth makes its annual journey around the sun.

On the earth, longitude is usually reckoned up to 180° east or west of the meridian of Greenwich, although it is sometimes reckoned up to 360°. It is occasionally reckoned in terms of time, 15° being equal to

1 hour of time. Thus a point on the earth may be described either as 75° 30′ west of Greenwich, or as 5 hours and 2 minutes west of Greenwich. On the celestial sphere longitude corresponds both to **right ascension** and to the **sidereal hour angle.** The former is usually reckoned in terms of time, and is always measured in the same direction, from west to east, the complete circumference of 360° being equal to 24 hours. The latter is always measured from east to west, from 0° at the vernal equinox up to 360°; it is equal to 360° minus the right ascension of a body. The sidereal hour angle has been introduced in the Air Almanac for greater ease in obtaining the Greenwich hour angle of a body.

The difference of longitude between the point directly beneath a heavenly body and the meridian of Greenwich is known as the **Greenwich hour angle (GHA)** of the body; the difference of longitude between the point directly beneath the body and the meridian passing through the position of the observer is known as the **local hour angle (LHA).**

For convenient reference and comparison, table 8 lists the various terms of the celestial sphere opposite the corresponding terms for the terrestrial sphere. Figure 177 shows these terms graphically.

TABLE 8.—*Coordinates of the celestial sphere and corresponding terms on the terrestrial sphere*

Terrestrial sphere	Celestial sphere
North Pole	North Pole.
South Pole	South Pole.
Equator......	Equator.
Latitude:	Declination:
North latitude__ __	North declination (+):
0° to 90° north of Equator.	0° to 90° north of celestial equator.
South latitude_____ ____	South declination (−)
0° to 90° south of Equator.	0° to 90° south of celestial equator.
Longitude:	Right ascension:
Reckoned from Greenwich___ .	Reckoned eastward from vernal equinox, or first point of Aries:
0° to 180° east or west of G.	0ʰ to 24ʰ east of ♈ (cf. "east longitude").
0ʰ to 12ʰ east or west of G.	Sidereal hour angle:
	Reckoned westward from vernal equinox, or first point of Aries:
	0° to 360° west of ♈ (cf. "west longitude").
	Greenwich hour angle:
	Difference of longitude between the point directly beneath the celestial body and the meridian of Greenwich.
	Local hour angle:
	Difference of longitude between the point directly beneath the body and the observer's meridian.

THE ASTRONOMICAL TRIANGLE

It is not essential that pilots understand, or even read, this section on the astronomical triangle. While a knowledge of the mathematical principles involved is desirable, and is of value in itself, the explanation presented elsewhere in this text is sufficient for practical purposes.

In spherical trigonometry, if any three parts of a triangle are known (whether sides or angles), the remaining three parts may be computed. The position of the star on the celestial sphere, the latitude and longitude of the assumed or dead reckoning position, and the observed time and altitude provide the information needed to compute the astronomical triangle and to obtain the data for the line of position. This is illustrated in figure 178, which shows the celestial poles, P and P', the equator, and the horizon. The earth is a tiny dot at the center of the celestial sphere,
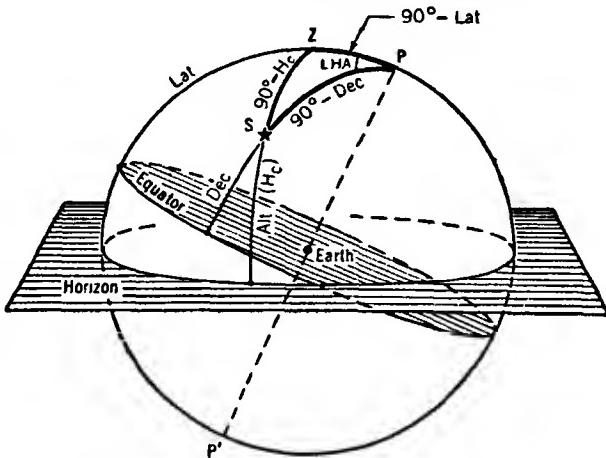
Figure 178.—The astronomical triangle.

and Z is the zenith, or the point directly above the *assumed or dead reckoning position* of the observer.

The circumference PZP' represents the meridian passing through the assumed position of the observer, and the arc PS is a portion of the meridian passing through the observed star S. The angle between these two meridians ZPS is the local hour angle, and the angle PZS is the azimuth of the star from the assumed position. Some students can visualize the triangle more readily if they think of it as projected down upon the earth; in this case P becomes the terrestrial pole, Z the assumed or dead reckoning position of the observer, and S the point directly beneath the star.

The arc from the equator to the star is the declination of the star, and is known from the Almanac. It is also known that the arc from the equator to the pole is 90°. Therefore, the side $SP = 90°$ — declination. If the star were south of the equator (in south declination), the side $SP = 90° +$ declination.

Since Z is the point directly above the assumed or dead reckoning position of the observer, the declination of the point Z is the same as the assumed latitude, and the side $ZP = 90°$ — latitude.

The local hour angle of the star may be known by combining the Greenwich hour angle of the star at the instant of observation (obtained from information in the Almanac), and the assumed or dead reckoning longitude of the observer.

From these three known parts, two of the remaining parts of the triangle are computed: the azimuth of the star, *PZS*, from the assumed position of the observer; and the side *SZ*, which is the distance from the star to the assumed position, or the radius of the circle of position through the assumed position. In figure 178 it is seen that the arc from the horizon to the zenith *Z* is 90°, and the computed altitude (H_c) of the star is therefore equal to 90° — *SZ*.

In order to save as much time as possible, the various navigation tables are so arranged that they may be entered directly with the declination of the star and the latitude of the assumed position (instead of 90° minus these quantities, as might be supposed from the above explanation); also, the computed altitude is obtained directly instead of the side *SZ*.

Unless the navigator happened to be exactly on the circle of position passing through the assumed or dead reckoning position when the sextant observation was made, the computed altitude will differ from the altitude observed. The altitude difference and the computed azimuth provide all the data needed for plotting the line of position, as illustrated in figure 176. If the observed altitude is greater than the computed altitude, the airplane was toward the star from the assumed position, and the altitude difference is therefore laid off toward the star; if the observed altitude was less, the airplane was farther away than the assumed position; see fig. 173.

THE SEXTANT OBSERVATION

Before actually making the sextant observation the navigator should be able to identify the star observed. It is as impossible to compute and plot on the chart a line of position from an unknown star as to plot a radio bearing from an unknown radio station. The identification of the stars and planets is not difficult, and is treated at the end of this chapter.

It is also important to select for observation stars that are favorably situated for the problem under consideration. The value of a line of position from a star directly along the line of flight, or from a star directly to the right or left of the aircraft, has already been pointed out. The more nearly two position lines are at right angles to each other, the more accurate is the fix obtained. An intersection at an angle of less than 30° is not desirable, although even this may prove of value in an emergency. It is desirable, then, that stars (or other bodies) should be observed which differ in azimuth by approximately 90°; if at all possible, they should differ in azimuth by not less than 30°. Because of the varying effect of refraction (p. 262) on the observation of a star near the horizon, the bodies selected should ordinarily be at least 15° above the horizon.

For celestial navigation by day there is, of course, little choice among the heavenly bodies. The sun is available, and, at times, the moon. At night, however, we have our choice of the stars, usually of one or more of the planets, and, about half the time, of the moon.

The moon, and the planets Venus and Jupiter, are so much brighter than the stars and are so easily identified that they tempt the beginner. With the Air Almanac, the computation of a line of position from one of these bodies is no more difficult than for the stars; all should be used from time to time as a matter of practice, in order to be able to use them quickly and with confidence if the need should arise.

The sextant observation is probably the most difficult step in the practice of celestial navigation. Certainly, it is the most important. No matter how accurate the computations, a line of position based on an inaccurate observation is still inaccurate.

Sextants are of various types, some making use of the natural (sea) horizon, others making use of an artificial horizon formed by a bubble level. Most bubble sextants can also be used with the natural horizon, if the horizon is visible. In some sextants the eyepiece is to be pointed directly at the celestial body, while in others the eyepiece is always horizontal, and the body observed is reflected through an arrangement of mirrors. In any case, good sextant observations are largely a matter of practice and of thorough familiarity with the instrument.

The bubble sextant is generally used in air navigation, since the natural sea horizon is often not available because the airplane is over land, or above clouds or haze, or because the horizon is obscured by darkness. Improved sextants, averaging a series of observations mechanically or visually, and incorporating other important advantages, have been developed and will be available to the public with the coming of peace.

After the observations are made and recorded, several corrections may need to be applied. One of these is for the **index error of the** instrument itself. Obviously, if an altitude of $0°5'$ is indicated when the reading should be $0°$, this same error will affect all altitudes measured with the instrument, and a correction for this error must be applied to all observations. It is often possible to adjust the sextant so that it does read correctly, and this correction becomes unnecessary. The method of adjustment will not be discussed here, since it is assumed that anyone who purchases an instrument will receive with it complete instructions on its care and adjustment. In the absence of detailed instructions for the adjustment of a particular sextant, general instructions of a very practical nature are contained in The American Practical Navigator (Bowditch), published by the United States Hydrographic Office. The correction for index error is usually abbreviated as I. C. (Index Correction).

If the natural horizon is used in taking the sextant observation (instead of the artificial bubble horizon), a correction must be applied for **dip,** or the height of eye of the observer. This is made necessary because the eye of the aviator is higher than the true horizon. In addition to the angle between a truly horizontal plane and the observed body, he also measures the small angle between the horizontal plane and the lower "horizon" which he sees below him. This small angle, therefore, must always be subtracted from the observed altitude.

When the natural horizon is used for an observation on the sun or moon, the altitude is taken when the reflection of the upper or lower edge (the "upper limb" or the "lower limb") of the body is brought into contact with the horizon. Since the altitude of the center of the body is required, it is clear that a correction for the **semidiameter** (half the diameter) of the body must be applied. Consequently, the semidiameter of the sun and of the moon is given for each day, on the corresponding page of the Air Almanac. If the lower limb is observed, the semidiameter must be added in order to find the altitude of the center; if the upper limb is observed, the semidiameter must be subtracted.

Additional corrections must be made for **refraction** and, in the case of the moon, for **parallax.** In one sense, it is immaterial whether the student understands the theory of these corrections or not; by means of tables given in the Air Almanac the application of the corrections is very simple. For the benefit of those who wish to understand the principles involved, the following brief explanation of these two corrections is given, but it may be passed over without reading, if desired.

In figure 179, the earth is represented, P and P' being the poles; HH is the horizon of an observer at O, S the star observed. A ray of light
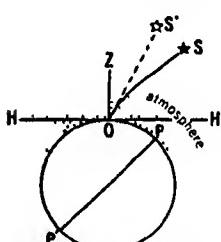
Figure 179.—Refraction.

from the star to the observer is bent by the effect of the earth's atmosphere, much the same as a stick partly submerged in water appears to bend where it enters the water. As a result of refraction, a star always appears to the observer to be slightly higher than it really is, at S' rather than at S, and the angle of elevation measured is always too large. As the star approaches the horizon its light must pass through a thicker section of the earth's atmosphere (OH), at a more oblique angle than when it is near the zenith (OZ) ; consequently the correction for refraction is greatest for bodies near the horizon and decreases with the altitude of the observed body above the horizon.

An additional correction for refraction must be made for observations made through the astro-dome, or "blister," provided for the navigator in recent bombers and transports. When the observer's head and sextant are properly positioned in the dome, the correction for the refraction of light passing through the dome is small, and a table of the necessary corrections is usually cemented to the dome. In the absence of such a table, the following corrections have been determined as correct, within a minute or two, for the standard astro-dome:

Sextant altitude	Correction
10°	−2′
20°	−3′
30° or more	−4′

The correction for parallax is illustrated in figure 180, in which the circle represents the earth, P, P' the poles of the earth, and M the moon. For an observer at O the altitude of the moon is represented by the angle h, but to be used for position determination all altitudes must be reduced to the horizontal plane through the center of the earth, where the altitude

is h'. The difference between the two angles, $h' - h$, is the parallax (as used in celestial navigation). By geometry it can be shown that the angle at $M = h' - h$, and therefore represents the parallax; it is the angle formed at the observed body by lines to the observer's position and to the center of the earth. From the figure it may be seen that the angle at M is greatest when the body is near the horizon and decreases to zero when the body is overhead. It is also evident that as the distance of the celestial
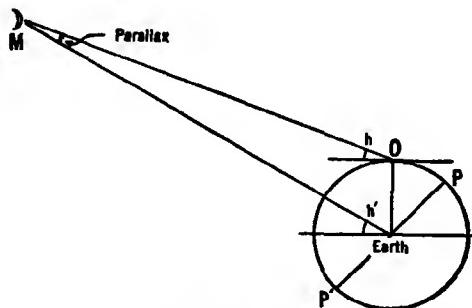
Figure 180. -Parallax.

body from the earth increases, the angle at M (parallax) becomes smaller. Parallax is of navigational importance only in the case of the moon, which is comparatively near the earth; the sun and planets are far enough from the earth that parallax is negligible, while the stars are at such infinite distances that it cannot be measured.

While considerable time has been used in explaining these corrections, with a little practice they can be taken from the tables and applied in a very few moments with little possibility of error.

Finally, when using a bubble sextant a correction may need to be applied for the effect of the earth's rotation. More than a century ago (1829) it was announced by Coriolis, a French physicist and mathematician, that the rotation of the earth causes moving objects to be deflected to the right (clockwise) in the northern hemisphere, to the left in the southern hemisphere. As a result, the horizon indicated by the bubble is misplaced so that, in the northern hemisphere, altitudes measured to the right of an aircraft are slightly too small; those to the left are slightly too large. This is true regardless of the direction of flight.

From the foregoing it may be seen that a line of position is always misplaced to the left of the track (in the northern hemisphere) and should be moved toward the right. In the southern hemisphere, of course, this rule is reversed. The line of position in each case should be moved in a direction at right angles to the track, in exactly the same way that a line of position is advanced in plotting a running fix (see p. 224). Shifting a few lines of position in accordance with these instructions should make it clear that no displacement results for a line of position at right angles to the track; maximum displacement occurs when the line of position is parallel to the track. The amount of this correction, which increases with

the velocity of flight and the latitude of the observer, is given in the following table. The corrections may be considered either as nautical miles or statute miles, according to the unit of ground speed with which the table is entered.

TABLE 9.—*Bubble sextant correction for the rotation of the earth.*

Ground speed (in mph)	Latitude									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
100	0	0	1	1	1	2	2	2	2	2
150	0	0	1	2	2	3	3	3	3	3
200	0	1	2	2	3	3	4	4	4	5
250	0	1	2	3	4	4	5	5	6	6
300	0	1	2	3	4	5	6	6	7	7
350	0	1	3	4	5	6	7	7	8	8
400	0	1	3	5	6	7	8	9	9	9

In the Air Almanac this is referred to as the "Z Correction for Bubble Sextant." It is accompanied by a second table giving a correction for a rather similar error due to the curvature of the track of an airplane because of precession, when steered by directional gyro or gyro-pilot. The algebraic sum of the two corrections may be used to enter another table in the almanac, in order to find a correction which may be applied directly to the observed altitude, instead of plotting the line of position and moving it as described. This is not recommended for general practice, however, as being more subject to error. There is reason to believe that gyros reasonably free from precession may soon be available, and that this part of the correction may become unnecessary.

In fact, many practical navigators disregard this entire correction for the earth's rotation, a practice which appears to be justifiable except for unusually fast aircraft in high latitudes.

THE AIR ALMANAC

The Air Almanac for each year is issued in three sections covering 4 months each. It is arranged so as to afford the desired information from a single page opening in most cases. The information for the sun, moon, and three planets has therefore been listed on a separate page for each day. The values for a. m. are given on the front of the page, and for p. m. on the back.

The data on the page for each day are tabulated at 10-minute intervals throughout the 24 hours. Two identical tables are provided for interpolating between the 10-minute tabulations, for the exact time of observation; see p. 297. One of these is on a flap which may be inserted facing the p. m. side of the page; the other is on the inside of the front cover. It is expected that the daily pages will be removed from day to day, leaving the interpolation table on the inside of the front cover always facing the a. m. side of the page for the current day. In either case, all the data that are needed for a solution for the sun, moon, or a

planet, may be obtained at one opening of the almanac. Tables for refraction and dip are on the back cover, and a convenient table is provided for converting an observed altitude of Polaris into latitude (see p. 300).

On the a. m. side of each daily sheet (p. 299), at the tops of the respective columns appear the names and the symbols representing the sun, three planets, and the moon. The stellar magnitudes of the planets (p. 283) are also indicated. Beneath each heading the GHA and the declination of the body is given for the hours tabulated.

Column 3 tabulates the GHA ♈; that is, the GHA of the vernal equinox. As explained later, this quantity is used in obtaining the GHA of a star. The GHA ♈ is also the Greenwich sidereal time, in terms of arc; it is, therefore, a tabulation of the Greenwich sidereal time for the corresponding Greenwich civil time.

The last column lists the correction for parallax, for observations of the moon. The plus sign is a reminder that this correction is always to be added to the sextant altitude. Near the bottom of this column are the corrections for semidiameter (S. D.) for the sun and for the moon. When interpolating for the GHA of the moon, under some conditions a slight error is introduced. A correction to eliminate this error, when needed, is given at the bottom of the same column, under "Corr. HA ☾."

The diagram at the right-hand edge of the sheet shows the positions of the moon, planets, vernal equinox, and four stars, with respect to the sun. The sun and moon are represented by their well-known conventional symbols. The stars and planets are identified by name. The diagram represents the narrow band along the ecliptic within which the sun, moon, and planets appear to move. The ends of the diagram are each 180° from the sun; that is, each half of the diagram represents a complete arc across the sky, from horizon to horizon. If the diagram is held toward the southern sky, with the symbol for the sun toward the eastern horizon (sunrise) and the west end toward the western horizon, the relative positions of the stars and planets near the time of sunrise may be visualized from the west half of the diagram. If the symbol for the sun is held toward the western horizon (sunset), with the east end toward the east, the other half of the diagram pictures the visible planets and selected stars near the time of sunset.

On the p. m. side (p. 298), the tables at the right show the time of rising and setting of the sun and moon, and the duration of civil twilight. The last column, under the heading of "Diff.," gives the number of minutes later at which the moon will rise or set on the following day.

The inside back cover (p. 301) lists the sidereal hour angle (SHA), right ascension (RA), and declination (Dec.) of 55 navigational stars. The Greenwich hour angle (GHA) of a star is obtained by adding the GHA of the vernal equinox (GHA ♈), as given in the daily pages, and the SHA of the star. As a convenient reminder, this equation is printed at the bottom of the page of star data:

$$GHA* = GHA ♈ + SHA*$$

DETERMINING THE GREENWICH HOUR ANGLE (GHA)

The GHA is determined from the Air Almanac, as illustrated by the ·following examples for the sun, a planet, the moon, and a star. These examples were arranged without regard to the position of the chosen body above or below the horizon, and serve only to illustrate the methods required for the various bodies. In each case, a Greenwich civil time (GCT) of 2126.4, April 18, 1944, is assumed.

Example 1.—GHA of the sun. From the table on p. 298 we find the GHA of the sun for 2120 GCT on Tuesday, April 18. From the table on p. 297 we find the correction for 6 min. 24 sec. (06.4). Adding these, the required GHA is obtained.

```
GHA  2120    __  ___ __ ___  _____ ____ _____ 140° 11′
Corr.    06.4 ___ ___ _____ __ ___  __ ___ ____ __ ___   1  36

GHA  2126 4  __ _____ _____ ___ ___ 141° 47′
```

Example 2.—GHA of Venus. From the table on p. 298, we find the GHA of Venus for 2120 GCT on April 18 and, from the table on p. 297, the same correction as in example 1, for 6.4 min. Adding these, the GHA is obtained.

```
GHA  2120    _____ ___ _____ ___ ____ 156° 47′
Corr.    06.4 .. -          .       ___ ___ _____ __ -    1  36

GHA  2126.4  _____ __ _ _____ 158° 23′
```

Example 3.—GHA of the moon. From the table on p. 298, we find the GHA for 2120 GCT. From the table on p. 297, under "Moon," the correction for 6.4 min. Adding these, the required GHA is obtained.

```
GHA  2120    _____ _____ ____ _ _ __ _____ . 189° 51′
Corr.    06.4 _          _       __ _    ____  ___      1  33

GHA  2126.4 .   _  __  _ _ _____ _____  _ ___ 191° 24′
```

Example 4.—GHA of Sirius. From the table on p. 298, we find the GHA ♈ for 2120 GCT, and from the table on p. 297, the same correction as in examples 1 and 2, for 6.4 min. From the table on p. 301, we obtain the SHA of Sirius. The required GHA is found by adding these three quantities.

```
GHA ♈ 2120   _____ _____  _____ 166° 52′
Corr.     06.4 ___ __  _____  _  _ __ _____ ... 1  36
SHA  Sirius _____ _   __ __ __ _____. .. _____ 259  20

GHA    2126.4 _____ 427° 48′
                                                  —360° 00′

                                                   67° 48′
```

When using sidereal time for any of the special methods, it is important to remember that a sidereal time interval is always shorter than the same number of hours and minutes of civil time, but when used for

angular measure (GHA or LHA) the two are equal. In both cases, a complete circumference of 360° is equal to 24 hours.

DETERMINING THE LOCAL HOUR ANGLE (LHA)

All conventional methods for computing a line of position require that the LHA be known. The LHA is found by combining the GHA of the body at the instant of observation with the longitude of the assumed or dead reckoning position.

Formulas have been evolved for obtaining the LHA for varying conditions of longitude and GHA, but they are generally difficult to memorize and apply. Remembering that GHA is always measured west from the meridian of Greenwich, in exactly the same way as west longitude, it is easy to sketch a time diagram for any possible condition, that will clearly indicate the simple arithmetic to be performed.

Figure 181 shows a series of time diagrams for obtaining the LHA under different conditions. In the figure, the circles represent the earth
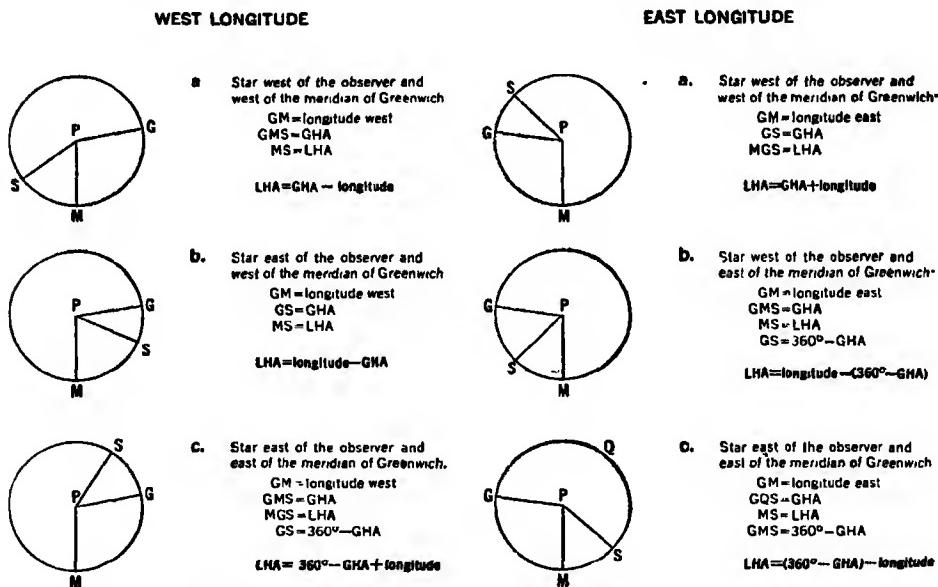
Figure 181.—Determining the local hour angle (LHA).

as it would appear looking straight down upon it from a point over the north pole. *P* is the pole and the circumference represents the equator; *PM* is the meridian passing through the position of the observer. Note that the meridian of the observer *PM* always takes the same position, below the pole, and the other points are located with reference to it. The diagrams at the left of figure 181 are for longitude 100° west; those at the right are for longitude 100° east. The construction of the diagram at the upper left is as follows:

With the meridian of the observer *PM* drawn in, the meridian of Greenwich *PG* can be drawn, about 100° east of *M*. The GHA of the star was about 155°, and the meridian passing through the star *PS* can now be drawn, with *S* about 155° west of Greenwich; that is, the angle *GPS* = 155°. The angle *MPS* is the local hour angle, and from the diagram it is clear that it is equal to the GHA of the star minus the longitude of the observer; LHA = 155° — 100° = 55°.

The LHA is usually measured from 0° to 180° east or west from the observer's meridian. It is desirable to note on the work sheet whether the LHA is east or west of the observer, to avoid error in laying off the azimuth and the altitude difference *a* toward or away from the star.

In some texts the time diagram is drawn with the observer viewing the earth from the *south* pole, and with the east-west relationships reversed. This seems unnatural, for people of the northern hemisphere at least, and is not recommended.

LINE OF POSITION TABLES

There are a number of tables specially designed to simplify solution of the astronomical triangle. Most of these incorporate some particular advantage which is preferred by some, while the features of another table are desired by others. Almost any of these tables are excellent for those who have learned to use them. A few of the more popular tables are briefly described in the following paragraphs:

H.O. 208 (*Dreisonstok*). This consists of two separate tables totaling 63 pages in one volume. Table I is entered with the latitude to the nearest whole degree, and an assumed longitude such that the LHA is also a whole degree. Four quantities are obtained from one page-opening of table I; one simple addition is performed, and three quantities are taken from table II. Three additions are then performed in order to obtain the computed altitude H_c and azimuth *Z*. The position assumed for easy use of the tables must be plotted on the chart before the line of position itself can be plotted. The table is useful for all latitudes and for all celestial bodies.

H.O. 211 (*Ageton*). This consists of one table of only 36 pages, in parallel "A" and "B" columns. It requires several more page-openings and slightly more arithmetic (addition and subtraction), but the method is simple and fewer rules are required. It may be conveniently used with the dead reckoning position or any convenient projection intersection, making it unnecessary to plot an arbitrarily assumed position on the chart before the line of position can be drawn. This table, also, is useful for all latitudes and for all celestial bodies. Pages 302 and 303 are from H.O. 211, and figure 182 shows the complete solution for a line of position using this table; the solution is described more fully on p. 270.

H.O. 214. This is one of the more recent tables for the purpose, consisting of eight volumes covering 10° of latitude each (0° to 80°). Volume VIII contains instructions for special methods for latitudes above

80°. Each volume contains about 240 large pages of tables, plus explanatory text and auxiliary information. For normal use, the tables are entered with an assumed position and an assumed declination, the altitude and azimuth are read directly, and a correction for the difference between the assumed and true declinations is obtained from an auxiliary table, to be applied to the tabulated altitude. Some find the bulk of these volumes objectionable, but the ease of solution has made these tables popular. Page 304 shows a portion of a page from H.O. 214. The dead reckoning position may be used, if desired, but the procedure in this case is more complicated.

H.O. 218 (*Astronomical Navigation Tables—"A.N.T."*). These are the most recent of all, reproduced by agreement with the British Air Commission. For the duration they are classified as "restricted," and are not available to the public. The tables are in 14 volumes of approximately 200 pages, covering only 5° of latitude each, from 0° to 70°. Each volume is in two parts, the first of which contains 4 pages for use with each of 22 navigational stars; the second part contains 4 pages devoted to each integral degree of declination. When using these tables, the azimuth and altitude are read directly. For a particular star, a small correction may need to be applied for the time elapsed since 1940 (the date for which the tables were computed); for an integral declination (when bodies other than the 22 selected stars are observed), a small correction for the difference in declination may need to be applied. In either case, convenient tables on the inside of the covers make this correction very easy and almost instantaneous. Page 305 is from Vol. G of H.O. 218, and p. 306 shows the correction for date to tabulated altitude of stars. Their use is explained more fully on p. 293. The normal correction for refraction is also included in the data tabulated, making it generally unnecessary to apply refraction when using these tables. On the back of the Air Almanac, a special "Table B" provides an additional correction for refraction for sextant observations taken from high altitudes.

COMPUTING THE LINE OF POSITION

A standard form for computing the line of position is not absolutely necessary, but for convenience, speed, and accuracy, a blank form is very desirable. One of the chief advantages of using a form is that it reduces the entire operation to a routine procedure which may be followed through correctly, even though the navigator has forgotten all the reasons why. The successive steps are presented in order, and the processes of addition or subtraction are clearly indicated.

The form adopted, of course, will vary with the particular tables to be used for the computation. Figure 182 shows one form, designed for use with H.O. 211. Some prefer a form arranged in a single column, and figure 183 shows such a form for use with H.O. 208, 211, 214 and 218.

The column designed for the tables being used should be cut out and laid at the edge of the page in the navigator's work book. Using the

entries of the form as a guide, problems are then worked out in parallel columns in the work book, to form a permanent record of the work done. The process of finding the LHA is identical for all methods, as is apparent from figures 182 and 183.

A fairly complete explanation of the solution shown in figure 182 should suffice for the forms shown in figure 183 as well. Any quantities still unfamiliar in the latter may be easily understood by reference to the explanatory text accompanying each of the tables.

Figure 182.—Form for computing altitude and azimuth, using H.O. 211.

In the upper left corner of figure 182 two rules are included, as a convenient reminder; their application will be discussed later. The only other rules required are the two which appear at the tops of the pages of the table itself. Below the rules on the form, spaces are provided for recording the date, the time, and the star or other body observed.

The abbreviation GCT stands for Greenwich civil time which is simply the standard time at Greenwich; the only difference is that Greenwich civil time is reckoned from 0 (at midnight) to 24 hours each day, instead of 0 to 12 and then repeating. That is, 2:40 p. m. would be written as 1440; 8:20 a. m. would be written as 0820. The navigator's watch should normally be set to keep Greenwich civil time, and should be reset or checked at least once every day by radio time signals. (See p. 278.)

The form is given the local date of April 20, but the GCT recorded is for April 21. The civil time where the observations were made (about

longitude 83°45′ W.) was about 9:52 p. m. (2152) eastern standard time, but the time at Greenwich was 5 hours later, nearly 3 hours past midnight and hence April 21. When this situation exists it should be noted on the form, to avoid any possibility of taking the values from the almanac for the wrong date.

The name of the observed body completes the general information at the upper left. At the upper right of figure 182, space is provided for recording a series of as many as 10 sextant observations, with the time of each observation. The 10 times and altitudes are both averaged, and the average time of the series and the average altitude are used in obtaining the line of position.

With the new averaging sextants, the average altitude for the series is read directly from the sextant. The average time for the series is obtained in different ways: some note the time of beginning and ending observations and use the average of the two; others observe 3 altitudes, note the time, and observe 3 more, using the time observed at the middle of the series as the average. In figure 182, if only the times at beginning and end of observation are averaged, the error amounts to 2 seconds, which can result in an error no greater than $\frac{1}{2}$ mile.

The abbreviation H_s is the altitude (height) actually measured with the sextant. Under Par (Parallax), Dip, Ref (refraction), S. D. (semi-diameter), and I. C. (index correction), any corrections for these items are entered. The total of these corrections (Corr.) is then applied to H_s to obtain H_o, which is considered as the observed altitude.

At the upper left of the part of the form used for the actual computations, there are two columns for obtaining the GHA of the observed body: one to be used for the sun, the moon, or any planet, the other to be used for a star. The first column is headed by the symbols for the sun ($\odot$), the moon ($\mathbb{C}$), and Venus (φ), the brightest of the planets; the second is headed by the symbol for a star (*). If the data for a star are being computed, it is recommended that the other column be crossed out to avoid confusion, and vice versa.

The GHA is next combined with the longitude to obtain the LHA, the relationship for this problem being as shown in the time diagram of figure 182. The declination (Dec.) of the star is taken from the Air Almanac. Then the A value of the LHA is taken from H.O. 211 (see p. 302), and the B and A values of the declination are taken from the table (see p. 302) and entered on the form as indicated. Now the A and B values in the first column headed "ADD," are added, obtaining another A value; this number is found in one of the A columns of the table, and the corresponding B value entered in the next two columns of the form. The A value is repeated in the last column, which we will now refer to as "column 4"; the preceding three columns will be referred to as columns 1, 2, and 3, respectively.

The subtraction indicated in column 2 results in the A value of "K," which is merely an auxiliary part introduced to facilitate solution of the astronomical triangle, but of no importance in itself. This A value is

found in the A columns of the table, when the value of K in whole degrees is read from the top or bottom of the column (in accordance with the rule at the top of each page of the table), and the additional minutes for K are read at the side, opposite the A value.

A rule at the top of the form reads "Give K same name as declination"—that is, if the celestial body is in north declination, K should be labeled North; if the body is in south declination, K should be named South. K is next combined with L (latitude) in accordance with the second rule at the top of the form, and the B value of this combination is entered in column 3. The two quantities in column 3 are added as indicated, resulting in the A value of H_c the computed altitude. The corresponding B value is obtained and entered in column 4; when subtracted there as indicated, the A value of the azimuth is obtained.

The azimuth as obtained from the tables is reckoned, for north latitudes, from the north up to 180° toward the east or west, depending on whether the body is east or west of the observer. In this case the azimuth is named N. 83°44' W., which means that the body is 83°44' toward the west from true north. This is equivalent to an azimuth of 276°16', measured from true north according to the conventional 360° system (see p. 45). The abbreviation Z_n indicates the conventional azimuth from true north.

The computed altitude H_c is now compared with the observed altitude H_o to obtain the intercept a, and the LOP (line of position) is then drawn toward or away from the body observed, according as the observed altitude is greater or less than the computed.

The process of computing a line of position is not nearly as difficult nor as time consuming as it sounds. Students may prove this to their own satisfaction by working out a few practical examples. By comparing figure 182 with the corresponding column of figure 183, it may be seen that both forms indicate identical procedures. With the use of some of the newer tables (especially H.O. 218), the computation is reduced to little more than taking the values from the tables, by inspection.

OTHER METHODS

There are several short-cut methods for obtaining the data for a line of position. For example, there are mechanical computers, on which the observed data and the information from the Air Almanac can be set up, and the answer can then be read directly from the instrument. By their use, some slight saving in time is effected, and any possibility of error in arithmetic is removed; but it is as possible to set up the data erroneously, on the computer, as to make a mistake in arithmetic, and in either case the results are worthless.

Another short cut is found in the use of precomputed altitudes. By this method, using the best data available, the estimated positions of the airplane along a projected route are determined by dead reckoning, for a series of regular time intervals. The altitudes and azimuths of the bodies selected for observation on the flight are then computed for the dead

reckoning positions and the corresponding times. These altitudes are then plotted in the form of a graph, against the proper time intervals, and a smooth curve is drawn through the points so obtained. The computed azimuths are each plotted on the chart of the route, from the dead reckoning positions to which they apply; see figure 192.

This method affords no saving in labor; its one advantage is that the labor is performed on the ground, before taking off, leaving a minimum of work to be performed in the air. The procedure while in flight may be outlined as follows:

Having obtained the corrected sextant altitude and noted the time of observation, as already described, read from the graph the precomputed altitude for the same time. The difference between the precomputed altitude and the observed altitude is the altitude difference (intercept) required for plotting the line of position.

If the time of observation coincides with one of the dead reckoning positions chosen for computing the curve, the azimuth is already plotted on the chart, and it is only necessary to lay off the altitude difference, from the dead reckoning position toward or away from the body according as the observed altitude is greater or less than the precomputed altitude. If the time of observation happens to fall between two of the dead reckoning positions used for the computations, a new dead reckoning position corresponding to the time of observation is plotted on the chart, and the azimuth is laid off by eye, in a direction roughly parallel to or intermediate between the azimuths plotted from the nearby positions; the computed altitude for the time of observation is read from the graph and compared with the observed altitude; and the altitude difference is then laid off as before, to obtain the line of position. If curves are precomputed and plotted for two or more celestial bodies, lines of position from each can be most quickly plotted, as already described, and their intersection fixes the position of the airplane.

H O NO 208	H O NO 211	H O NO 214	H O NO 218
GCT	GCT	GCT	GCT
GHA	GHA	GHA	GHA
CORR	CORR	CORR	CORR
GHA	GHA	GHA	GHA
LONG (A)	LONG	LONG (A)	LONG (A)
LHA	LHA	LHA	LHA
LAT (A)	DEC		LAT (A)
		DEC	
DEC	LHA (A)	LAT (A)	ALT
b	DEC $\dot{b}$		a $\dot{d}$ CORR
$b \sim$ DEC	RA	H	Hc
		Δd CORR	Ho
A	DEC A	Hc	a
$\overset{+}{b}$	RB	Ho	
LOG Hc	K A	a	TAB z
Hc	K		TRUE z
Ho	L	z	
a	K−L B	Δd CORR	
	K ~ L	z	
c	R $\dot{b}$		
D	Hc A		
C+D	Hc		
z	Ho		
z	a		
z			
	R A		
	Hc $\bar{B}$		
	Z A		
	z		

Figure 189.—Forms for computing altitude and azimuth, arranged in columns.

Any difference between the actual position of the airplane and the dead reckoning position does not affect the accuracy of the line of position, provided only that the azimuth and altitude difference are laid off from the dead reckoning position on the plotted route as determined from

the original data used in precomputing the altitude curve, rather than from any data obtained during the flight.

If desired, the corrections for index error, refraction, etc., can be applied to the precomputed altitudes, with reversed signs, when plotting the curve. In this way, sextant altitudes can be used without applying these corrections, still further reducing the work required while in the air.

One of the simplest methods is provided by the "star altitude curves." In this method, intersecting circles of position from three stars are printed on the same graph in different colors. The altitudes of the stars for which the curves have been drawn are observed in quick succession, and the Greenwich sidereal time (see p. 265) of the observations recorded. It is then necessary only to note the point of intersection of the curves corresponding to the altitudes observed, and read from the margins of the graph the latitude of the observer's position and the local sidereal time at that place. Combined with the Greenwich sidereal time by ordinary arithmetic, the local sidereal time affords the longitude.

This method is subject to the disadvantage that it cannot be used by day and is available for relatively few stars at night. For satisfactory results, not more than a minute should elapse between the two altitude observations; if more time does elapse, a method is provided for carrying forward the curve corresponding to the first observation.

A further development of the star altitude curves is provided by the astrograph. With this instrument properly installed in an aircraft, the star curves are projected directly upon an outline Mercator chart, scale 1:1,000,000 at latitude 56° north. The film containing the star curves incorporates a graduated time scale, by means of which the time of observation is easily set against the particular meridian selected as the "setting longitude" for a given flight over the charted area. Curves are for only two stars for any given time, but a correction is noted along the time scale which, applied to an observation of Polaris, affords latitude and, in effect, provides a third star. All the work required may be performed before beginning the flight, and the circle of position is projected on the chart without plotting. If an appreciable time interval must elapse between two observations, the first circle of position can be sketched on the chart and advanced in the usual manner. Like the original star curve method, the astrograph has a very limited choice of stars for observation; additional disadvantages are the special charts required and the possibility of mechanical failure. ·

Other simple methods have been developed, or rediscovered, during the war, designed for an approximate determination of position in life-raft navigation, with little or nothing in the way of instruments.

One such method provides for the determination of latitude from the duration of daylight, simply by noting the time when the sun first peeps above the horizon in the morning, and the time when it just sinks below the horizon in the evening. Longitude is also determined from the time of sunrise or sunset.

Another method considers that a "sextant observation" of 0° has

been taken for the lower limb of the sun, when the time is noted as it is just tangent to the morning or evening horizon. Refraction under these conditions is uncertain, but an approximate line of position is possible.

Still another method makes use of the Polynesian system of determining position from the star directly overhead at a given time. This makes use of a special chart of the stars, with a means for showing them in their correct relation to geographic features for any instant of time.

The ancient method for the determination of latitude from the meridian altitude of the sun (or any other body) is also of interest. For example, the altitude of the sun is measured by sextant, or by other simple means, when it is at its highest point, due south of the observer, at noon. A simple diagram such as figure 184, shows how easily latitude can be determined when the sun's declination is known.

In the figure, the observed altitude was $60°$, and the declination of the sun is known to be $20°$ N. at time of observation. The angle X clearly
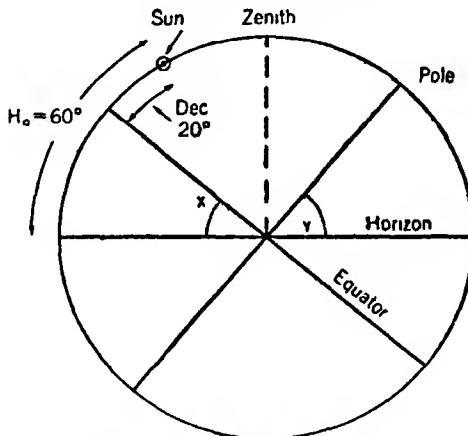
Figure 184. Latitude by meridian altitude.

is equal to $60° — 20°$, or $40°$; since the angle between the earth's axis and the equator is $90°$ (a right angle), angles $X + Y$ are also equal to $90°$, and the angle $Y = 90° — X$, or $50°$. Since the elevation of the pole is equal to the latitude of the observer, the latitude is determined as $50°$. A shorter solution points out that the arc from the horizon to the zenith is equal to $90°$, and the arc from the sun to the zenith (the zenith distance) is therefore equal to $90° — 60°$ (the H_o), or $30°$. From the equator to the zenith, then, is $20° + 30° = 50°$; that is, the "declination of the zenith" in this case is $50°$—and there is a rule that "**the declination of the zenith is the observer's latitude.**"

A LINE OF POSITION FROM POLARIS

In the case of Polaris, a line of position may be obtained with very little computation, the line of position being the parallel of latitude on which the observer is located.

As suggested on page 251, the altitude of the celestial pole is equal to the latitude of the place from which it is observed; however, Polaris

is not exactly at the pole, but moves about it in a small circle with a radius of about 1° (see fig. 185). Now if the altitude of the pole is equal to the latitude, it is apparent that when Polaris is directly above the pole the radius of 1° must be subtracted from the altitude of the star in order to find the altitude of the pole—and hence the latitude of the place. If
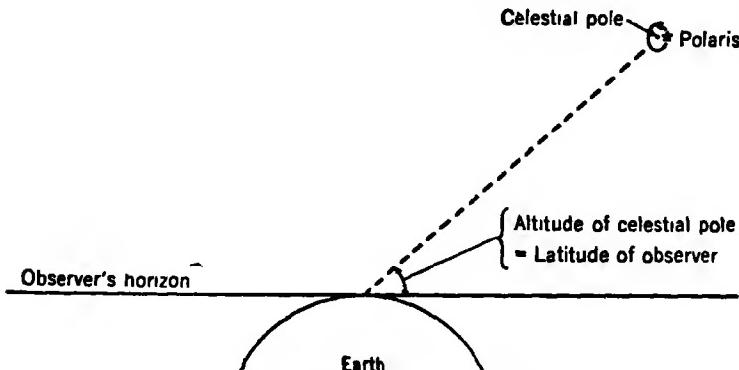
Figure 185.—Latitude by Polaris.

the star is directly below the pole, the radius of 1° must be added to the altitude of the star in order to obtain the altitude of the pole; if the star is directly to the right or to the left of the pole, the altitude of the star is the same as the altitude of the pole.

In the Air Almanac there is a special table (see p. 300), giving the correction to be applied to an observed altitude of Polaris for various values of the LHA ♈ (local hour angle of the vernal equinox). The GHA ♈ is taken from the daily sheet of the Air Almanac, and combined with the longitude of the assumed position in the usual way in order to obtain the LHA ♈. With this LHA the special table is entered and a correction obtained which is to be added to or subtracted from the observed altitude H_o, as indicated. The result is the latitude of the observer, which is most easily plotted on the chart as a line of position.

The process of taking and recording 5 to 10 sextant observations, computing the data, and plotting the line of position on the chart will probably require not less than 10 minutes. That is, after obtaining one line of position about 10 minutes may elapse before a second can be plotted on the chart. During this period a fast airplane can cover 30 to 50 miles, and the first line of position must be carried forward the course and distance made good by dead reckoning between the two observations, just as described in connection with radio bearings, on page 224. Similarly, the resulting fix must be carried forward the distance and direction made good after the second observation, in order to obtain the current position of the airplane. If Polaris is selected as the second star, the distance that the first line of position or the fix must be carried forward is reduced to a minimum because of the shorter time required for computing and plotting a line of position (latitude) from Polaris.

A LINE OF POSITION FROM AN UNIDENTIFIED STAR

Assume that a trans-Atlantic flight is in progress, and that the airplane has been enveloped in clouds for several hours; the radio has failed, and a position from celestial observations is urgently required. Finally a break appears in the clouds and a single star of about the first magnitude, or brighter, is seen for only a few minutes. In this brief interval, four sextant altitudes of the star are obtained, but since the identity of the star is unknown, the necessary data for computing the line of position cannot be taken from the Air Almanac. By some method, the star must be identified before the line of position can be computed.

A few stars, such as Sirius and Vega, possess such distinctive characteristics that they can usually be identified, even if no other stars are visible, but under conditions of haze or partial cloud even these stars may be difficult to recognize individually. For the most part, a star is identified by its position with reference to known star groups (such as the Great Dipper) more than from its individual appearance.

There are available several star finders, such as the Rude Star Finder and Identifier (published by the U. S. Hydrographic Office) from which, after the approximately known data are set up, the star may be identified. There are also special Star Identification Tables, H.O. No. 127, by means of which the star may be identified with but little difficulty. In addition, most of the tables commonly employed can be used for star identification. Figure 186 shows a form designed for use with H.O. 211.

The method is basically simple, but, like most other methods, it requires enough time that it would not be used in air navigation except under extreme conditions. It consists essentially in working the ordinary problem backward in order to find the declination and LHA of the star observed; with these values approximately found, the SHA can be determined and the star can be identified in the Air Almanac. The problem is then worked in the usual way (as in fig. 182) in order to obtain the line of position. In figure 186 the problem just presented is worked out.

As shown on the form, the mean time for the series of observations was 2342 GCT, April 18, 1944; the observed altitude H_o was 19°45′; and the azimuth of the star was estimated as 55° east of true north. The A value of the azimuth is added to the B value of the corrected altitude, and the result A 11296 is obtained in column 1. This total is repeated in column 4, and the B value corresponding to it is written in columns 2 and 3 as indicated. The subtraction required in column 2 is now performed to obtain the A value of K; K and L are combined as in figure 182, and the B value of the combination added as indicated in column 3. This results in the A value of the declination of the star observed; the corresponding B value is then subtracted as required in column 4, to obtain the A value of the LHA which is marked east, from the known direction of the star. The declination is marked north or south in accordance with the rule appearing on the form.

On the circle (time diagram) which appears on the form, the meridian of Greenwich is now drawn in, 30° east of *M* (the observer's meridian) and also the meridian of the star, approximately 105° east of *M*. Next, the GHA ♈ for 2342 GCT on April 18, 1944, is obtained from the Air Almanac as 202°27′, and added to the time diagram, about 202° to the west of *G*.

WORK SHEET — STAR IDENTIFICATION

If Z is greater than 90° take K from bottom of table

Give K same name as Latitude

Take Dec from top of table,
    give Dec. same name as Latitude UNLESS
    both Z and K-L are greater than 90°

Take LHA from:
    TOP of table when K is greater than L;
    BOTTOM of table when K is less than L.

Date   *April 18, 1944*

GCT   *23ʰ 42ᵐ 00ˢ*

Star   _____

Assumed latitude   *50° N*

     longitude   *30° W*

GCT			Hₛ
Hr	min	sec	°
23	*40*	*15*	*19 28*
	41	*23*	*19 47*
	42	*57*	*19 48*
	43	*45*	*20 08*
	166	*120*	*191′*
23	*42*	*00*	Hs *19° 48′*

S D	Par	Dip	Ref	I C	Corr	*–3′*
			–2	*–11*	H₀	*19° 45′*
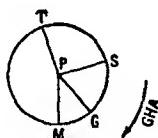
		ADD	SUBTRACT	ADD	SUBTRACT
Z (est) *N 55 E*		A. *8663*			
Hₑ *19° 45′*		B. *2633*	A. *47119*	B. *19595*	A. *11296*
		A. *11296*	B. *19595*		
K *32° 03′ N*			A. *27524*		
L *50° N*					
K~L *17° 57′*				B. *2126*	
Dec *37° 20′ N*				A. *21721*	*9957*
LHA *104° 09′ E*					*1339*

Figure 186.—Form for star identification, using H.O 211.

From the relationship pictured, the GHA of the star is equal to 360°—74°09′ or 285°51′. (Note: The 74°09′ was obtained by subtracting the assumed longitude from the LHA.) The SHA of the star is equal to the GHA of the star minus the GHA ♈: 285°51′ — 202°27′ = 83°24′.

At the right side of the page of star data in the Air Almanac (see p. 301), stars are listed in order of increasing SHA. Running down the list, we find 81°15′ SHA, and declination 38°44′ N., for the zero magnitude star Vega. No other star even approaches these values, and it is therefore safe to assume that Vega was the star observed. The data for Vega are therefore entered on the form shown in figure 182, and the line of position computed as before.

RADIO TIME SIGNALS

The exact time is of great importance to accurate navigation, both at sea, and in the air. For this reason, radio time signals are broadcast

from Annapolis, San Francisco, Pearl Harbor, and from Balboa (Canal Zone), during the last five minutes of the hour, at frequent intervals during the day. The regular hours and frequencies are changed from time to time, but the Naval Observatory, Washington, D. C., will furnish full information to those interested, on request.

Beginning at 5 minutes before the hour, a signal is transmitted each second except the twenty-ninth, to the fiftieth. From the fiftieth second to the end of the minute, signals are broadcast as shown in table 10. Vacant spaces in the table indicate the omission of a signal. Note that the number of signals in the group ending on the fifty-fifth second of each minute indicates the number of minutes yet to be broadcast. The beginning of the sixtieth signal of each minute marks the exact beginning of the following minute.

With this arrangement of signals, the navigator is afforded many opportunities to check his watch during the 5 minutes, instead of merely waiting for the long dash at the end of the hour. For example, the watch may be checked on the thirtieth and sixtieth second of each minute.

TABLE 10.—*Schedule of Radio Time Signals*

Minutes	Seconds										
	50	51	52	53	54	55	56	57	58	59	60
55	—		—	—	—	—					—
56	—	—		—	—	—					—
57	—	—	—		—	—					—
58	—	—	—	—		—					—
59	—										—

In addition to the time service of the U. S. Naval Observatory described above, the U. S. Bureau of Standards broadcasts time signals continuously on frequencies of 5 and 10 megacycles during the 24 hours of the day and night; also on 15 megacycles during the daylight hours and on 2½ megacycles at night. These signals are so arranged that time checks can be had at any time. A complete description of the signals is broadcast by voice just after the beginning of each hour and half-hour.

In order to make full use of the advantages of some of the short methods, a navigator may wish to carry a watch rated to and set for sidereal time. With the Air Almanac and the radio time signals it is very easy to set the exact sidereal time on a watch.

For example, suppose that the sidereal time corresponding to 2100 GCT on April 18, 1944 is desired (see p. 298). For 2100 GCT, the GHA ♈ is 161°51′. It has already been pointed out that the GHA ♈ is the GST (Greenwich sidereal time) in terms of arc. From a table in the almanac for the conversion of arc to time, it is seen that 161°51′ = 1047:24 (10 hours 47 min. 24 sec.). Accordingly, the sidereal watch is set for that time and started going when the radio time signal for 2100 GCT is received.

IDENTIFICATION OF STARS

It has already been pointed out that it is useless to observe the altitude of a star unless the identity of the star is known. The beginner is apt to be confused by the number of stars, and to suppose that it is difficult to distinguish one star from another. On the contrary, stars differ from one another considerably, in relative brightness, in color, and in their peculiar groupings. The Air Almanac lists 55 principal navigational stars, all of which are shown on the navigational star chart in the back of the almanac.

Any flat map has its difficulties. This is painfully apparent in the star chart of the Almanac, in which the poles are stretched out into lines extending all the way across the chart. Globes are not so convenient to carry
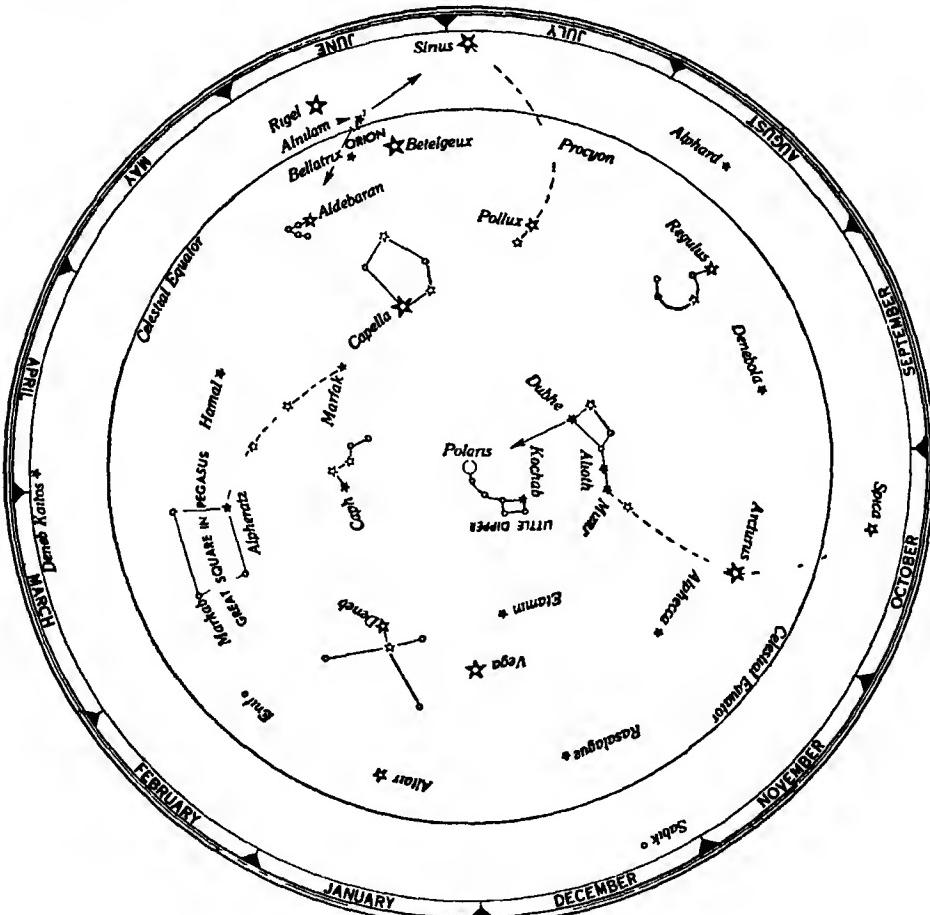
Figure 187　Navigator's star map, northern hemisphere.

USE OF THIS MAP

This map may be oriented by holding it overhead and toward any group of stars (as the Great Dipper), and turning it until the positions of stars on the map correspond to the positions of the same stars in the sky. All other stars in that part of the map will then point to the stars in the sky which they represent.

For an observer in the northern hemisphere, this map may also be oriented by holding it overhead with the current month toward the north, the southern part of the map will then show the relative positions of stars between the zenith and the southern horizon of the observer as they will appear at local midnight. Stars toward the east and west will also be properly oriented

When using the map before or after midnight, it should be turned clockwise or counterclockwise, respectively; one month of the border scale is equal to 2 hours.

about, but the serious student will be well repaid for the purchase of a good celestial globe, some of which may now be had quite reasonably. With a globe, the astronomical triangle and celestial coordinates can be clearly seen; the relation between civil and sidereal time can be demonstrated, and the approximate solutions of navigational problems can be obtained graphically. With any good star chart, however, and a little patience, it is not difficult to identify any or all of the principal stars, if we start from some familiar group.

Figures 187 and 188 are included in this text as an aid to star identification. In these figures the 55 principal navigational stars are shown in solid black, and are named. Only the star patterns which help to identify
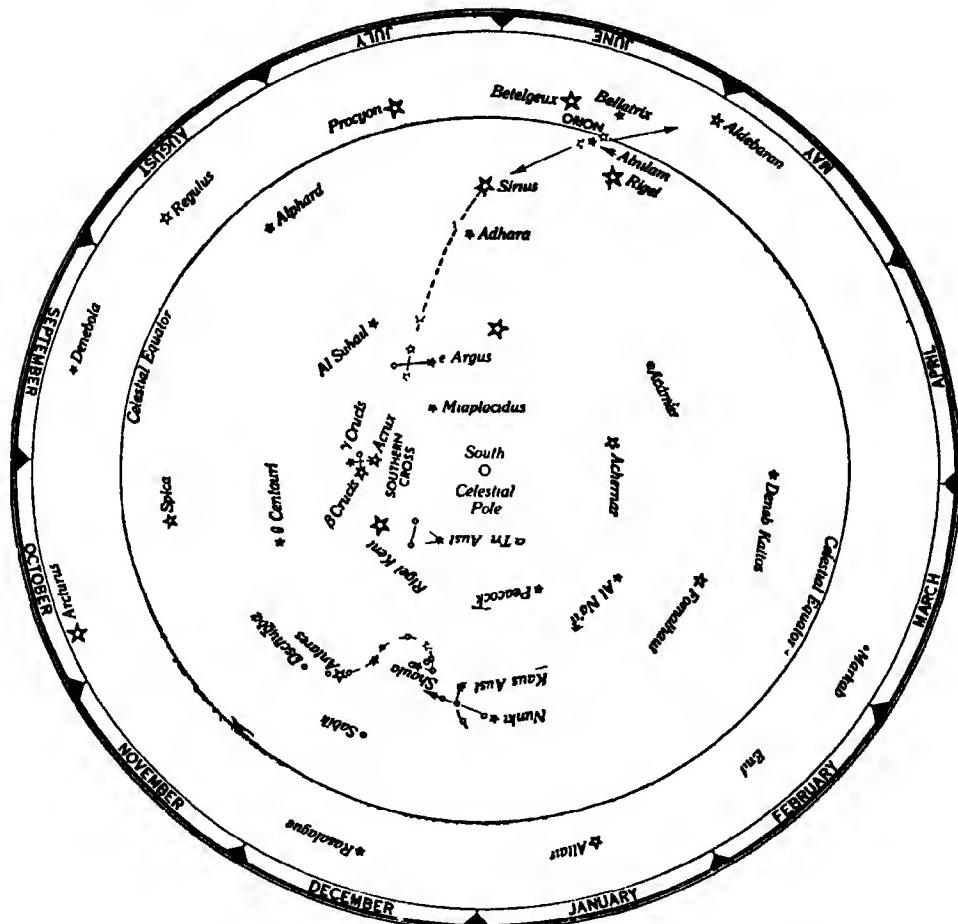
Figure 188 Navigator's star map, southern hemisphere.

USE OF THIS MAP

This map may be oriented by holding it overhead end toward any group of stars, then turning it until the positions of stars on the map correspond to the positions of the same stars in the sky. All other stars in that part of the map will then point to the stars in the sky which they represent.

For an observer in the southern hemisphere, this map may also be oriented by holding it overhead with the current month toward the zenith; the northern part of the map will then show the relative positions of stars between the zenith and the northern horizon of the observer as they will appear at local midnight. Stars toward the east and west will also be properly oriented

When using the map before or after midnight, it should be turned counterclockwise or clockwise, respectively.

the navigator's stars are shown,.in outline, with broken lines connecting them and tracing out the pattern.·

For example, everyone is familiar with the "Big Dipper" which is part of the constellation (star group) known as Ursa Major. Most people are also aware that the two "pointer stars" in the bowl of the dipper point to Polaris, the North Star. The star nearer the pole is named Dubhe, the other Merak. Now, if we follow the curving handle of the dipper, extending the curve beyond the dipper about the length of the dipper itself, we come to the bright yellow star Arcturus, in the constellation Boötes. Continuing the same curve about an equal distance again we find the star Spica, in Virgo, a little fainter than Arcturus and blue-white in color.

On the opposite side of Polaris from the Big Dipper, and about the same distance from it, is an easily recognized W (or M, depending on the position), which is the distinguishing feature of Cassiopeia. Two of the stars in the W are named in the Air Almanac: Caph and Ruchbah. Toward the south from the W, and about as far from it as the W is from the pole, is "the great square in Pegasus," two of the four stars of the square being Alpheratz and Markab.

The constellation of Orion is the brightest and most conspicuous star group visible from the northern hemisphere. Its distinguishing characteristic is the group of three stars in "Orion's belt," with the bright stars Betelgeux and Rigel about equidistant on each side of them. The writer is always able to distinguish between these two stars by remembering that Betelgeux was described by the ancients as "the ruddy shoulder star"—and it is distinctly reddish in color. Rigel is definitely blue-white.

The three stars in Orion's belt point almost directly toward Sirius, the brightest star in the heavens, toward the southeast. In the opposite direction from the belt stars and at about the same distance as Sirius, is Aldebaran, which is also reddish in color and still further identified by the "V" of faint stars (The Hyades). With Betelgeux as a center, if an arc is swung northward from Sirius, it will pass through Procyon and Pollux, all at about the same distance from each other as Sirius is from the belt stars. Procyon represents the "Little Dog," Sirius the "Big Dog," which further helps to identify these neighboring bright stars. Pollux is accompanied by his twin brother, Castor, just slightly fainter than Pollux.

In the same way, a few at a time, all the navigational stars may be learned.

STAR NAMES

For centuries, the brighter stars have been known by special names, as Sirius and Vega. They also have another name, consisting of a letter of the Greek alphabet and the possessive form of the constellation name. Thus, Alpheratz is also known as α Andromedae. In celestial geography this is about the same as a city and state name, α being the city and

Andromeda the state. We may have α Andromedae and α Cassiopeiae, just as we have Portsmouth, N. H., and Portsmouth, Va. Only a few of the navigator's stars are referred to by their Greek-letter names, but for convenient reference the Greek alphabet is given in table 11.

TABLE 11.—*The Greek alphabet*

Letter	Name	Letter	Name	Letter	Name
α	Alpha.	ι	Iota.	ρ	Rho.
β	Beta.	κ	Kappa.	σ	Sigma.
γ	Gamma.	λ	Lambda.	τ	Tau.
δ	Delta.	μ	Mu.	υ	Upsilon.
ε	Epsilon.	ν	Nu.	φ	Phi.
ζ	Zeta.	ξ	Xi.	χ	Chi.
η	Eta.	ο	Omicron.	ψ	Psi.
θ	Theta.	π	Pi.	ω	Omega.

BRIGHTNESS OF STARS

Stars are classified as first magnitude, second magnitude, etc., according to their apparent brightness. A first magnitude star is 2½ times as bright as a second magnitude star, and so on; conversely, a second magnitude star is ⅖ as bright as a first. Antares and Spica are first magnitude stars; Polaris is second magnitude.

A few stars are brighter than first magnitude, and are classified in order of increasing brightness as 0, —1 or —2 magnitude. Sirius, the brightest star, is —2 magnitude; Arcturus is 0 magnitude, which is one magnitude brighter than first.

In the preceding paragraphs the nearest whole magnitudes are given, as is usually done in speaking of them. Astronomers determine magnitudes to the nearest hundredth, and each whole magnitude includes approximately half a magnitude on either side of it. Thus, first magnitude extends from 0.51 to 1.50, second from 1.51 to 2.50, and so on. In the Air Almanac magnitudes are tabulated to the nearest tenth, Sirius being listed as —1.6 (nearest whole magnitude —2).

THE PLANETS

The stars are self-luminous like the sun, which is our nearest star; the planets (of which the Earth is one) shine only by light reflected from the sun, just as the moon does. Of our sun's family of planets, only four are of interest to the navigator: Venus, Jupiter, Saturn, and Mars. They can usually be distinguished by their steady light, which does not twinkle like the light from a star.

Venus is easy to recognize, since it is brighter than any star; it is golden yellow in color and is often called the evening star, or the morning star, since it is rarely seen more than 3 hours after sunset or 3 hours before sunrise.

Jupiter is a little fainter than Venus, but brighter than Sirius, the brightest star. It is, therefore, also very easy to identify.

Saturn is about as bright as a first magnitude star and is pale yellow in color.

Mars is decidedly red in color, and varies in brightness from second magnitude (as bright as Polaris) to minus 3 magnitude, which is between Jupiter and Venus in brightness.

The sun and its planets, including the earth, all appear to move along approximately the same path or plane in the sky, known as the ecliptic, which may be defined as the intersection of the plane of the earth's orbit with the celestial sphere. Frequently there are one or more planets to be seen at night, and it is not difficult to visualize the approximate position of the ecliptic, along the line connecting them. If at any time a bright star is seen near the ecliptic where none is shown on the star maps, it is fairly certain to be one of the four planets mentioned above.

MOTION OF THE STARS AND PLANETS

All are familiar with the way in which the sun rises in the east, climbs up the sky on an inclined path until noon, when it is toward the south (for an observer in the United States), and circles downward to set in the west. In exactly the same way the stars and planets pass across the night sky from east to west. Stars close to Polaris, the North Star, do not set. They describe small circles around it and never pass below the horizon, passing from view in the daytime only because of the greater brightness of the sun. As the distance from the north pole increases, the radii of the circles increase until, near the southern horizon, stars describe only flattened arcs not very high above the horizon.

For an observer in south latitudes, of course, this is reversed in some details. Stars (or other celestial bodies) that are farther north than the observer, rise in the east and follow an inclined path up the sky to a point north of the observer, then descend to set in the west. Stars close to the south celestial pole do not set, but describe small circles around the pole. As the distance of the star from the south celestial pole increases, the radius of the circle increases until, near the northern horizon, stars describe only flattened arcs.

Aside from this nightly passage of the stars across the sky, their apparent motions in space with respect to each other are so slight that they are spoken of as "fixed," and the star patterns or constellations remain unchanged for millenniums. By way of contrast, there is an appreciable motion of the sun and planets against the background of the stars, even from day to day. In spite of this, the new arrangement of the Air Almanac makes it as easy to determine positions from these bodies as from the stars. This is all the more important since they are the brighter and therefore the more easily observed bodies.

Some of the subjects mentioned briefly in this final section, such as the motion of the stars and planets, may be considered as general astronomy. They are not essential to the practice of celestial navigation. If

these elements are known, however, the various problems are more clearly understood, and may be solved more intelligently and quickly. Those who desire to study the subject further are referred to some of the standard texts listed on p. 344, and also to any of the better encyclopedias.

THE PRACTICE OF CELESTIAL NAVIGATION

In all methods of navigation it is essential that the pilot maintain constant headings and air speed for satisfactory results. In celestial navigation, in addition, the aircraft must be held straight and level while sextant observations are made. Movements about the longitudinal axis of the aircraft will have the greatest effect on observations of bodies to the right or left; observations of bodies ahead of or behind the aircraft will be most affected by changes in air speed. A definite system of signals should be arranged so that the pilot may know when the navigator is about to take observations, and may concentrate on flying as steadily as possible.

Time will be saved in observation if the navigator knows in advance what bodies he intends to observe, and their positions with respect to the direction of flight. The approximate altitude of each body should usually be set on the sextant before beginning observation. The work is further simplified if an assistant is available to record the time of observation upon signal from the navigator.

Since a line of position from Polaris (latitude) requires a minimum of time to compute and plot, it might well be one of the stars selected, whenever it is visible. One line of position does not afford a fix, but it may still afford very useful information. For example, if the line is approximately parallel to the track of the aircraft the pilot may know whether he is making good the desired track and, if not, the distance off-course. If the line of position is approximately at right angles to the track, it furnishes a definite check on the distance made good, and also on the ground speed.

For the reasons just stated, it is good practice to obtain a fix at the end of climb, when the aircraft has leveled off at cruising altitude; subsequent fixes, referred to this point, help to establish ground speed at cruising altitude. If the point of departure is used as the assumed position for this first observation, the intercept is a direct measure of the distance made good, and of the ground speed to that point. Similarly, if the destination is used as the assumed position and a fix is obtained about an hour before the estimated time of arrival, the intercept is the distance yet to go, and a more accurate estimate of the arrival time can be made.

In order to facilitate selection of the most advantageous bodies for observation for a given flight, a pamphlet of "Sky Diagrams," has been issued by the Nautical Almanac Office for trial use. It consists of two pages of sky diagrams for each month, for latitudes 10°, 30°, 50° and 70° N., and 10° and 30° S., at intervals of 2 hours throughout the night.

Figure 189 is the diagram for 0300 LCT (3:00 a. m., local civil time), April 1944, for latitude 10° S.

Each diagram is, in reality, a small-scale star map, and the cross at the center represents the observer's zenith. An arrow has been added to the diagram of figure 189 to represent the direction of flight (030° in this case), with a broken line at right angles to the direction of flight. By inspection, it is apparent that star number 22 will be directly ahead of the aircraft at this time, with star number 7 directly off the left side.

STARS

1	Achernar	12	Dubhe
2	Acrux	13	Fomalhaut
3	Aldebaran	14	Peacock
4	Alpheratz	15	Pollux
5	Altair	16	Procyon
6	Antares	17	Regulus
7	Arcturus	18	Rigel
8	Betelgeuse	19	Rigel Kent
9	Canopus	20	Sirius
10	Capella	21	Spica
11	Deneb	22	Vega

MOON

① Position on April 1

② Position on April 2

· · · · · · · · · · · ·

POLES

N P North　　　S P South

MAGNITUDE SCALE

ALTITUDE SCALE

The positions of the stars are shown for the fifteenth of the month

Figure 189.—Sky diagram for latitude 10° S., at 0300 LCT, April 1944, with legend.

From the legend, which has been reproduced (in part) beside the diagram, it is seen that these stars are Vega and Arcturus; and from the altitude scale of the legend, their altitudes will be approximately 35° and 45°, respectively.

In approaching a small objective in an area devoid of landmarks (such as a small island after a long over-water flight), it is often desirable to fly deliberately to one side of the destination, then approach it along a line of position. This is much more efficient than attempting to hit the destination "on the nose," flying to and beyond the estimated time of arrival, and then being uncertain whether to turn right or left. In following this procedure, it is well even to allow for any uncertainty in the dead reckoning position of the airplane.

To illustrate the procedure just described, suppose that an airplane is approaching Island X, figure 190, when an LOP (line of position) from the sun is obtained, intersecting the plotted course at F. All navi-

gational data fix F as the position of the airplane with a possible error no greater than 15 miles. Therefore, a circle-of-error of 15-mile radius is drawn around F, and the position may be anywhere within the circle. If we assume that the airplane is at the southerly side of the circle of error, then the line to A represents the maximum change of course necessary to insure approaching the island from the north. The LOP through the island may be reached anywhere between points A and B. Well in advance of the estimated time of reaching the LOP through AB (10 or 15 minutes) another sun line is obtained and plotted as a "preliminary LOP." This line is advanced to pass through the island, the distance
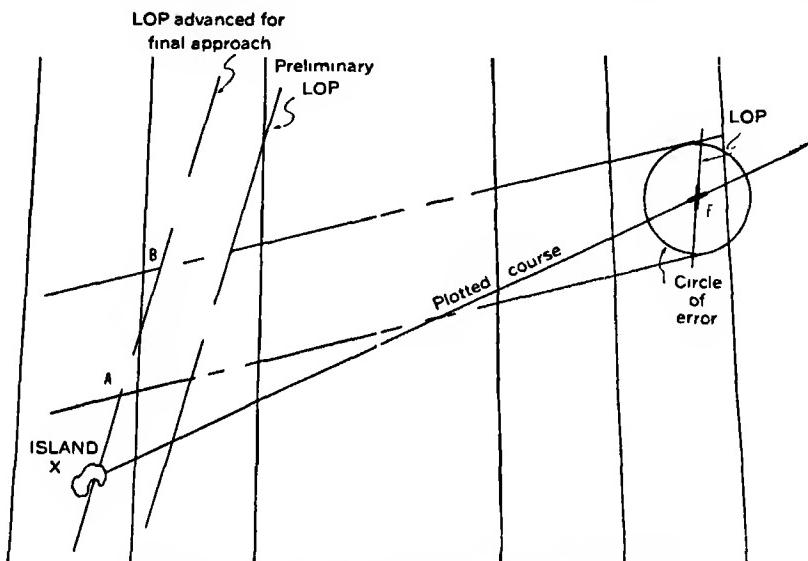
Figure 190   Approaching the destination along a line of position.

between the two lines is measured, the aircraft continues until this distance is made good, and is then turned along the LOP for the final approach to the island.

The direction and magnitude of the intercepts from two bodies may be used for orientation or "quadrant identification," as in radio range flying; they also provide the angle of approach toward the destination. In figure 191, an aircraft was being flown toward Island X along the plotted course shown, but at the estimated time of arrival the island could not be seen. For the ETA the computed altitudes of stars 1 and 2 are known, and may be represented by the lines of position shown passing through the island. If altitudes of the two stars are observed in quick succession, and both intercepts are AWAY from the lines through the island, it is apparent that the aircraft is in the northwest quadrant; if both intercepts are TOWARD, it is in the southeast quadrant. If the LOP from star No. 1 is AWAY and that from star No. 2 is TOWARD, the northeast quadrant is indicated; and in the reverse case, the southwest quadrant is identified.

If the LOP from No. 1 is 15′ AWAY and the LOP from No. 2 is 15′ TOWARD, the aircraft is in the northeast quadrant and on the bisector of the quadrant; the true course to the island is therefore 225°, and the distance to go is equal to the hypotenuse of a right triangle, the sides of which are 15 nautical miles each (about 21 miles). If the LOP from No. 1 is 30′ AWAY and the LOP from No. 2 is 15′ AWAY, the aircraft is
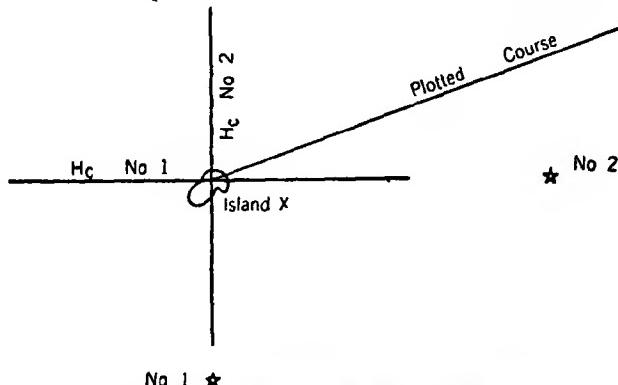
Figure 191.—Orientation and angle of approach by comparison of intercepts.

in the northwest quadrant; the true course to the island may quickly be determined as about 153°, and the distance is the hypotenuse of a triangle with sides of 30 miles and 15 miles (nearly 34 miles). These sides can be laid off on the grid of a computer, and the value of the hypotenuse quickly obtained.

EXAMPLES

Example 1.—A pilot flying "over the top" by dead reckoning, believed his position to be about latitude 37°30′ N., longitude 99°30′ W., when he was able to obtain a series of altitudes of the sun.

Having made the necessary computations with the aid of his preferred navigation tables, these data are available:

Azimuth (bearing) of the sun	235°
Observed altitude, H_o	42°34′
Computed altitude, H_c	42°20′
Altitude difference, a	14′

The azimuth, or bearing, of the sun is laid off from the dead reckoning position of the airplane. The altitude difference of 14 minutes (equal to 14 minutes of latitude) is measured on any convenient meridian, and laid off along the bearing, toward the body (since the observed altitude is greater than the computed altitude). A line drawn at right angles to the bearing through the point so obtained is the required line of position.

The intersection of this line of position with a second line obtained by observing the moon (if visible by daylight), or the intersection of lines of position from two stars at night, fixes the location of the airplane.

Example 2.—A nonstop flight is planned from Los Angeles municipal airport to LaGuardia Field, New York City. The flight is to be made at 20,000 feet, April 18, 1944. From the best data available, a ground speed of 287 mph is expected (265 mph cruising speed plus 22 mph assistance along the course from a WNW wind of 30 mph).

The distance as scaled from the planning chart is about 2,475 miles, and approximately 8 hours and 40 minutes are required for the flight. From the daily page of the Air Almanac (see p. 298) it is found that the sun sets in the latitude of New York on this date at about 1841 local civil time, or 7:41 p. m., E.W.T. It is desired to land at New York about 1 hour before sunset, at 1740 LCT; the departure from Los Angeles is therefore set for 8 hours 40 minutes earlier, or 10:00 a. m., E.W.T.— 7:00 a. m., Pacific war time, 1400 GCT.

The dead reckoning positions of the airplane for each hour, beginning at 11 o'clock E.W.T., about 1 hour after take-off, are determined, and each position is assigned a number corresponding to the eastern war time when the airplane should be at that place. The dead reckoning positions at these time intervals are as shown in figure 192.
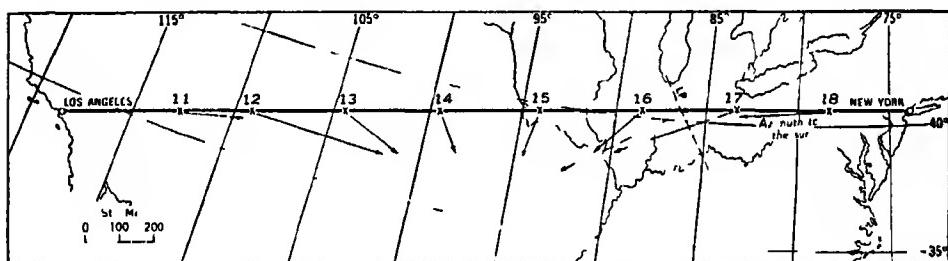
D R POSITION	LATITUDE	LONGITUDE	E WT	G CT	AZIMUTH	ALTITUDE	ALTITUDE (corr for ref)
11	35°32'	113°54'	1100	1500	93°19	23°35	23°36'
12	36°57'	109°12'	1200	1600	107 38	38°57	38°58'
13	38°08'	104°22'	1300	1700	128°27	52°20	52°21'
14	39°08'	99°14'	1400	1800	161°37	60°42	60°42'
15	39°56'	93°58'	1500	1900	202 02	59°24'	59°24'
16	40°30'	88°35'	1600	2000	232°17	49°26'	49°27'
17	40°49'	83°09'	1700	2100	252°05	35°35'	35°36'
18	40°52'	77°42'	1800	2200	267°00'	20°23	20°24'

Figure 192 Data for route from Los Angeles to New York.

Using the latitude, longitude, and GCT corresponding to each dead reckoning position, as shown in the table of figure 192, the altitude and azimuth of the sun for each position are computed. From the refraction table on the back of the Air Almanac, the corrections for refraction are applied, with reversed sign. During flight, then, the only corrections to be applied to sextant observations of the sun are those for index error, astro-dome, and Coriolis (if the latter is considered worth while). The azimuths from the various dead reckoning positions are laid off, and the precomputed altitude curve of figure 193 is plotted and drawn.

PRECOMPUTED CURVE PLOTTING SHEET
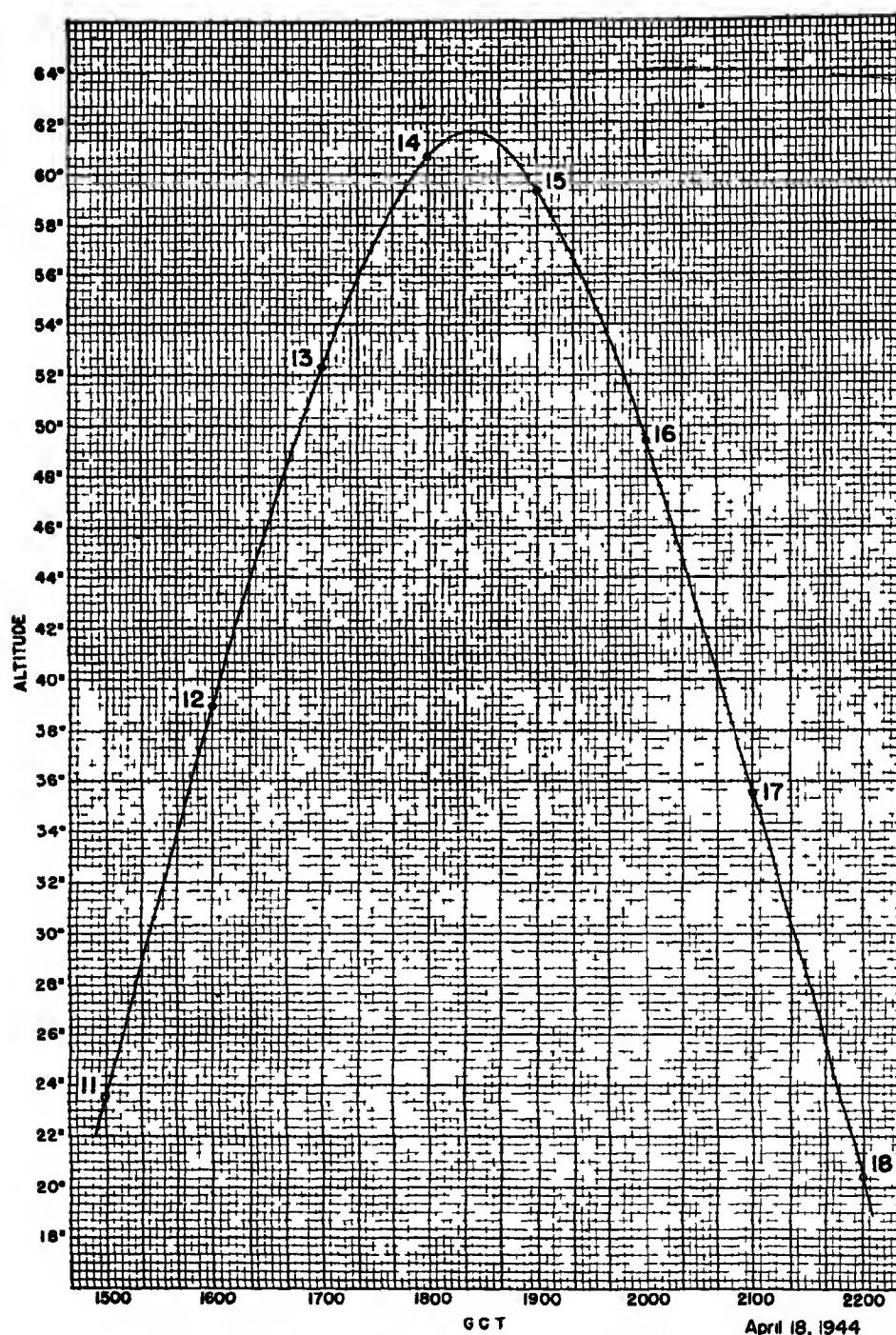
Figure 193.—Precomputed altitude curve for the sun.

To illustrate the use of the method in flight, suppose that at 2030 GCT a sextant altitude of 42°52′ is obtained. Applying a known index correction of —1′, and a correction of —4′ for dome refraction, the corrected sextant altitude is 42°47′. From the curve of figure 193 the altitude of the sun for 2030 is read as 42°35′. Since the observed altitude is 12′ greater, the position at the time of observation is 12′ closer to the sun. At 2030 the dead reckoning position of the airplane is halfway between positions 16 and 17; the approximate azimuth of the sun is laid off through that point, as indicated by the light broken line, and the line of position LP is drawn 12′ toward the sun from the dead reckoning position. If desired, an azimuth curve can be constructed in the same way as the altitude curve, affording the true azimuth for any desired GCT.

At night, precomputed altitude curves for two or more bodies (stars, planets, or moon) can be constructed. Lines of position can be obtained in each case as simply as in the problem just described, and a fix can be obtained practically without computation.

Example 3.—On a night flight, high above an overcast, a position is required, using the star altitude curves. With this method the correction for refraction is incorporated in the curves themselves, and the only corrections necessary (when using the bubble sextant) are the corrections for index error, astro-dome, and Coriolis. The following observed altitudes were obtained: Vega, 39°35′; and Polaris, 37°58′.

The appropriate page is selected, as shown in figure 194, and the intersection of the (interpolated) curves is found near the upper left corner of the page. Opposite the intersection, at either side of the page, the latitude of the observer is read as 38°58′. Directly above the intersection the LST (local sidereal time) of the observer's position is read as 1409.5. For this method, the simplest procedure is to carry a chronometer set for GST (Greenwich sidereal time). The GST of the observations for this problem was noted as 2016.5. Subtracting 1409.5 from 2016.5 gives the longitude of the observer in terms of time, as 0607 (6 hrs. 07 min.), which is equivalent to a longitude of 91°45′. No computation other than this one subtraction is required.

At the bottom of the page of star curves, the scale of LST is in terms of arc. For those who do not wish to carry a chronometer rated to sidereal time, the GCT of observation is noted, as usual. The corresponding GST (GHA ♈) is easily obtained from the Air Almanac in terms of arc, and the subtraction described above gives the longitude directly in terms of arc (degrees and minutes) from Greenwich.

Vega was observed first, and Polaris immediately afterward. The average time of the observations of Vega was used for both stars, as the altitude of Polaris changes so slowly. The line from the intersection of the two altitude curves to the side of the page is always drawn parallel to the upper and lower borders, not parallel to the altitude curves. In this case, the curves for Polaris are very nearly parallel to this line; on other pages, the curves for Polaris may be at an appreciable angle to the upper and lower borders.
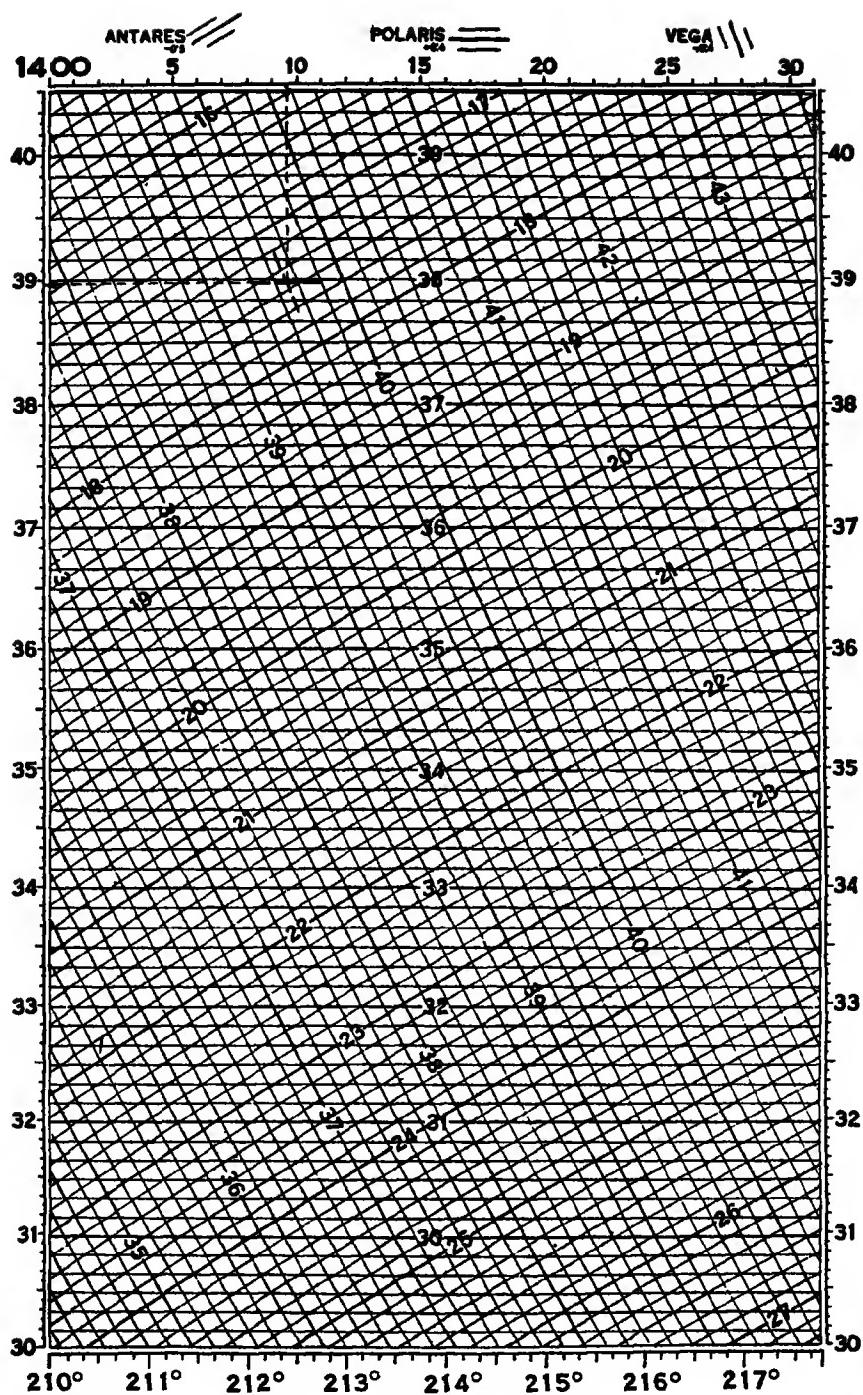
Figure 194.—A fix by star altitude curves.

Example 4.—On April 3, 1944, at dead reckoning latitude 32°27′ N., longitude 95°45′ W., at 0345 GCT (= 2145 LCT, April 2), after all corrections were applied the observed altitude of Arcturus was 34°01′. Find the computed altitude and azimuth, using H.O. 218. Note that the normal correction for refraction need not be applied when using these tables.

The LHA is obtained in the usual way as 61°26′ E., but in these tables LHA is always measured westward, and is therefore 298°34′ W. When using these tables confusion will result in determining azimuth unless this usage is followed. In order to enter the tables with a whole degree of latitude and a whole degree of hour angle, an assumed position of latitude 32° and longitude 95°19′ is adopted for this problem, making the LHA 299° W. (61° E.).

From the proper page for Arcturus in H.O. 218 (see p. 305), under latitude 32° and for HA 299° (in the right margin) the following data are found:

Alt.	t	Az.
34°23′	—8	87°

At the bottom of the page it is stated that no correction for date (t) is necessary until 1944. In the table on the inside of the front cover (see p. 306), under $t = 8$ and opposite 1944, a correction of 1′ is indicated; the minus sign given for t indicates that the correction is to be subtracted, and the computed altitude H_c is therefore 34°22′.

For azimuth, the rule at the bottom of the page for Arcturus reads: "For argument HA on the right, True Azimuth = Tabulated Azimuth." Since the HA in this case, 299°, was found in the right margin, the tabulated azimuth of 87° is correct.

The assumed position (lat. 32°, long. 95°19′) is plotted, and from it the azimuth of 87° is measured, and the intercept (34°22′ — 34°01′ = 21′ of latitude) is laid off from the assumed position AWAY from the star, since the observed altitude was less than the computed. The LOP is then drawn through the point so obtained, at right angles to the azimuth.

SPECIMEN PAGES

Pages 297 to 301 are from the Air Almanac for 1944. Pages 302 to 306 are from H.O. 211, H.O. 214, and H.O. 218. These specimen pages are included to illustrate the use of the almanac and the various tables in the solution of typical examples.

QUESTIONS

1. Under what conditions is celestial navigation practical today?

2. With present equipment, what accuracy can normally be expected for a fix from sextant observations?

3. Distinguish between a circle of position, a circle of equal altitude, and a line of position.

4. As the point beneath a star is approached, does the altitude of

the star increase or decrease? What is the relation between the change of altitude and the distance from the sub-stellar point?

5. Can position be determined from one sextant observation?

6. State the relationship between the latitude of a place and the altitude of the celestial pole.

7. What information can be obtained from a single line of position?

8. Why might the starting point or the destination sometimes be used as the assumed position?

9. What celestial coordinates correspond to the following terrestrial terms: latitude? longitude? difference of longitude?

10. What is the relation between right ascension and sidereal hour angle?

11. What is meant by the "astronomical triangle"?

12. What three parts of the astronomical triangle are usually known in celestial navigation, and how are they obtained?

13. What is meant by the "intercept," and what use is made of it?

14. Why is a single sextant observation unreliable in air navigation?

15. Name the various errors likely to be included in a sextant observation, and the sources from which corrections can be applied.

16. For how many celestial bodies is the correction for parallax important?

17. What is meant by the "Coriolis effect," and how may it be corrected?

18. What is meant by Greenwich sidereal time? How is it different from the GHA ♈?

19. What is a time diagram, and how may one be constructed?

20. How does the LHA differ from the GHA?

21. What advantage is there in being able to work from a dead reckoning position, or any convenient projection intersection, rather than from some position arbitrarily assumed for easy use of tables?

22. What is the advantage of using a standard form for computing a line of position?

23. What is the difference between the H_s and the H_o?

24. Describe the construction and use of precomputed altitude curves.

25. How are the printed star altitude curves used?

26. What is the astrograph? What are its advantages and disadvantages?

27. How may latitude be obtained from an observation of Polaris?

28. Describe the methods by which the navigator may be sure he has the correct time.

29. How may a line of position be obtained from an unidentified star?

30. Are stars usually identified by their apparent size and brightness, their color, or their relation to other stars?

31. Which is brighter: a star of zero magnitude, or a first magnitude star? how much brighter?

32. Why are planets not shown on star maps?

33. Name the four planets of interest to navigators, with their distinguishing characteristics.

34. What is meant by a "fixed star"? How many stars are fixed?

35. What positions of stars relative to the moving aircraft are usually considered most desirable for observation?

36. What is the surest method of approaching a small objective, such as an island, after a long over-water flight?

PROBLEMS

The following problems may be solved by working from the specimen pages, pp. 297 to 306.

1. What is the time of sunrise on April 18, 1944, for a place at latitude 30° N.? 60° N.? 30° S.?

2. Convert the times of sunrise in question 1 to central war time; to GCT.

3. What is the time of moonset on April 18, 1944, at latitude 70° N.? 20° N.? 40° S.?

4. Convert the answers in question 3 to eastern standard time and GCT.

5. What is the GST of 1414:14 GCT, April 18, 1944? Of 2121 GCT on the same date?

6. Is the duration of evening twilight longer at the equator, or at latitude 70° N., on April 18, 1944?

7. From the headings on p. 298 arrange the planets Venus, Mars, and Jupiter in order of brightness.

8. On April 18, 1944, at 2247 GCT, the observed altitude H_o of Polaris was 33°47'; dead reckoning longitude, 84°35'. Determine the latitude of the observer.

9. For dead reckoning latitude 38°00' N., longitude 32°39' W., for GCT 2320, April 18, 1944, determine the computed altitude and azimuth of Arcturus.

10. For 0345 LCT on April 19, 1944, at dead reckoning latitude 34°00' N., longitude 73°07' W., compute the altitude and azimuth of Arcturus.

11. Nearly simultaneous observations of three stars were obtained, as follows: Polaris 35°00'; Antares 22°00'; Vega 42°00'. The average GST for the series of observations was 1909. Determine the latitude and longitude of the point of observation by means of the star altitude curves, figure 194.

The following problems will require general tables or charts, or both:

12. A direct over-the-top flight is to be made from Houston municipal airport to Brainard Field, Hartford, Conn. Cruising altitude is 10,000 feet; true air speed at predicted conditions 213 mph; wind is forecast as 270°, 30 mph. The flight is planned for arrival at sunrise, May 3, 1943. Determine the GCT for the take-off at Houston and for the arrival at Hartford; also, compute and plot altitude curves for Antares

and Deneb. When the curve for Deneb reaches altitude 60°, change from Deneb to Alpheratz.

13. The GHA of a star at a certain time is 125° and its declination 47°00′ N. If your position is at latitude 41° N., longitude 99° W., determine from plate I your distance (in degrees and minutes of arc) from the sub-stellar point. What should the star's altitude be? What is its LHA?

14. On plate II plot the following data to obtain a fix:

Assumed position: lat. 32° N.; long. 96° W.

Star No. 1: $H_o = 27°49′$; $H_c = 27°57′$; Az. $= 73°$
Star No. 2: $H_o = 39°23′$; $H_c = 39°19′$; Az. $= 349°$

What is the latitude and longitude of the resulting fix?

15. Assume that after observing star No. 1, the airplane was flown for 13 minutes at 225 mph, making good a track of 135° true, before star No. 2 was observed. What latitude and longitude are obtained from a plot of this running fix?

16. Determine the computed altitude H_c and azimuth from true north Z_n for each of the following:

Lat.	Long.	GHA	Dec.	H_c	Z_n
32° 00′ N	77° 15′ W	183° 27′	14° 24′ N		
47° 15′ N	116° 30′ W	67° 30′	18° 39′ S		
42° 00′ S	69° 24′ W	350° 36′	9° 12′ N		
15° 43′ N	95° 20′ E	195° 40′	15° 43′ S		
63° 00′ N	150° 30′ E	271° 30′	23° 27′ N		

17. On May 5, 1944, at 0300 GCT, the following observations were obtained:

Spica: $H_o = 40°56′$
Regulus: $H_o = 61°07′$

The dead reckoning position was at latitude 31°00′ N., longitude 95°30′ W. Compute the necessary data and plot the lines of position on plate II, to determine the latitude and longitude of the fix.

Sample page from "American Air Almanac."

INTERPOLATION OF GHA

SUN, PLANETS ♈

Int	Corr	Int	Corr	Int	Corr
00 00	0 00	03 17	0 50	06 37	1 40
01	0 01	21	0 51	41	1 41
05	0 02	25	0 52	45	1 42
09	0 03	29	0 53	49	1 43
13	0 04	33	0 54	53	1 44
17	0 05	37	0 55	57	1 45
21	0 06	41	0 56	07 01	1 46
25	0 07	45	0 57	05	1 47
29	0 08	49	0 58	09	1 48
33	0 09	53	0 59	13	1 49
37	0 10	57	1 00	17	1 50
41	0 11	04 01	1 01	21	1 51
45	0 12	05	1 02	25	1 52
49	0 13	09	1 03	29	1 53
53	0 14	13	1 04	33	1 54
57	0 15	17	1 05	41	1 55
01 01	0 16	21	1 06	45	1 56
05	0 17	25	1 07	49	1 57
09	0 18	29	1 08	53	1 58
13	0 19	33	1 09	57	1 59
17	0 20	37	1 10	08 01	2 00
21	0 21	41	1 11	05	2 01
25	0 22	45	1 12	09	2 02
29	0 23	49	1 13	13	2 03
33	0 24	53	1 14	17	2 04
37	0 25	57	1 15	21	2 05
41	0 26	05 01	1 16	25	2 06
45	0 27	05	1 17	29	2 07
49	0 28	09	1 18	33	2 08
53	0 29	13	1 19	37	2 09
57	0 30	17	1 20	41	2 10
02 01	0 31	21	1 21	45	2 11
05	0 32	25	1 22	49	2 12
09	0 33	29	1 23	53	2 13
13	0 34	33	1 24	57	2 14
17	0 35	37	1 25	09 01	2 15
21	0 36	41	1 26	05	2 16
25	0 37	45	1 27	09	2 17
29	0 38	49	1 28	13	2 18
33	0 39	53	1 29	17	2 19
37	0 40	57	1 30	21	2 20
41	0 41	06 01	1 31	25	2 21
45	0 42	05	1 32	29	2 22
49	0 43	09	1 33	33	2 23
53	0 44	13	1 34	37	2 24
57	0 45	17	1 35	41	2 25
03 01	0 46	21	1 36	45	2 26
05	0 47	25	1 37	49	2 27
09	0 48	29	1 38	53	2 28
13	0 49	33	1 39	57	2 29
17	0 50	37	1 40	10 00	2 30
21		41			

MOON

Int	Corr	Int	Corr	Int	Corr
00 00	0 00	03 20	0 49	06 39	1 37
02	0 01	24	0 50	43	1 38
06	0 02	29	0 51	47	1 39
10	0 03	33	0 52	52	1 40
14	0 04	37	0 53	56	1 41
18	0 05	41	0 54	07 00	1 42
22	0 06	45	0 55	04	1 43
26	0 07	49	0 56	08	1 44
31	0 08	53	0 57	12	1 45
35	0 09	58	0 58	16	1 46
39	0 10	04 02	0 59	20	1 47
43	0 11	06	1 00	25	1 48
47	0 12	10	1 01	29	1 49
51	0 13	14	1 02	33	1 50
55	0 14	18	1 03	37	1 51
01 00	0 15	22	1 04	41	1 52
04	0 16	27	1 05	45	1 53
08	0 17	31	1 06	49	1 54
12	0 18	35	1 07	54	1 55
16	0 19	39	1 08	58	1 56
20	0 20	43	1 09	08 02	1 57
24	0 21	47	1 10	06	1 58
29	0 22	51	1 11	10	1 59
33	0 23	56	1 12	14	2 00
37	0 24	05 00	1 13	18	2 01
41	0 25	04	1 14	23	2 02
45	0 26	08	1 15	27	2 03
49	0 27	12	1 16	31	2 04
53	0 28	16	1 17	35	2 05
58	0 29	20	1 18	39	2 06
02 02	0 30	25	1 19	43	2 07
06	0 31	29	1 20	47	2 08
10	0 32	33	1 21	52	2 09
14	0 33	37	1 22	56	2 10
18	0 34	41	1 23	09 00	2 11
22	0 35	45	1 24	04	2 12
26	0 36	49	1 25	08	2 13
31	0 37	54	1 26	12	2 14
35	0 38	58	1 27	16	2 15
39	0 39	06 02	1 28	21	2 16
43	0 40	06	1 29	25	2 17
47	0 41	10	1 30	29	2 18
51	0 42	14	1 31	33	2 19
55	0 43	18	1 32	37	2 20
03 00	0 44	23	1 33	41	2 21
04	0 45	27	1 34	45	2 22
08	0 46	31	1 35	50	2 23
12	0 47	35	1 36	54	2 24
16	0 48	39	1 37	58	2 25
20	0 49	43		10 00	2 25
24					

Correction to be added to GHA for interval of GCT

STARS

No	Name	Mag	SHA	Dec	No	Name	Mag	SHA	Dec
1	Achernar	0 6	336 06	S57 31	12	Dubhe	2 0	194 55	N62 03
2	Acrux	1 1	174 07	S62 47	13	Fomalhaut	1 3	16 22	S29 55
3	Aldebaran	1 1	291 49	N16 24	14	Peacock	2 1	54 42	S56 55
4	Alpheratz	2 2	358 38	N28 47	15	Pollux	1 2	244 32	N28 10
5	Altair	0 9	62 59	N 8 43	16	Procyon	0 5	245 54	N 5 22
6	Antares	1 2	113 31	S26 18	17	Regulus	1 3	208 39	N12 14
7	Arcturus	0 2	146 43	N19 28	18	Rigel	0 3	282 02	S 8 16
8	Betelgeux	0 1 1 2	271 58	N 7 24	19	Rigil Kent	0 3	141 03	S60 36
9	Canopus	−0 9	264 19	S52 40	20	Sirius	1 6	259 20	S16 39
10	Capella	0 2	281 52	N45 57	21	Spica	1 2	159 26	S10 52
11	Deneb	1 3	50 07	N45 05	22	Vega	0 1	81 15	N38 44

Complete Star List on inside back cover.   Jan.–Apr., 1944

Sample page from "American Air Almanac."

GREENWICH P. M. 1944 APRIL 18 (TUESDAY)

GCT	☉ SUN GHA	Dec	♈ GHA	VENUS –3.3 GHA	Dec	MARS 1 3 GHA	Dec	JUPITER –1 9 GHA	Dec	● MOON GHA	Dec
12 00	0 10	N10 53	26 29	18 51	N 2 29	284 23	N24 50	248 37	N16 43	55 01	S14 03
10	2 40		28 59	19 20		286 53		249 07		57 26	01
20	5 10		31 29	21 50		289 23		251 38		59 50	14 00
30	7 40 ·		34 00	24 20 ·		291 53 ·		254 08 ·		62 15 ·	13 58
40	10 10		36 30	26 50		294 23		256 39		64 39	56
50	12 40		39 01	29 20		296 53		259 09		67 04	55
13 00	15 10	N10 54	41 31	31 50	N 2 30	299 24	N24 50	261 39	N16 43	69 28	S13 53
10	17 40		44 01	34 20		301 54		264 10		71 52	51
20	20 10		46 32	36 50		304 24		266 40		74 17	50
30	22 40 ·		49 02	39 20 ·		306 54 ·		269 11 ·		76 41 ·	48
40	25 10		51 33	41 50		309 24		271 41		79 06	48
50	27 40		54 03	44 20		311 54		274 11		81 30	45
14 00	30 10	N10 54	56 33	46 50	N 2 31	314 25	N24 50	276 42	N16 43	83 55	S13 43
10	32 40		59 04	49 20		316 55		279 12		86 19	41
20	35 10		61 34	51 50		319 25		281 43		88 44	40
30	37 41 · ♪		64 05	54 20 ·		321 55 ·		284 13 ·		91 08	38
40	40 11		66 35	56 50		324 25		286 43		93 32	36
50	42 41		69 06	59 19		326 55		289 14		95 57	35
15 00	45 11	N10 55	71 36	61 49	N 2 33	329 26	N24 50	291 44	N16 43	98 21	S13 33
10	47 41		74 06	64 19		331 56		294 15		100 46	31
20	50 11		76 37	66 49		334 26		296 45		103 10	29
30	52 41 ·		79 07	69 19 ·		336 56 ·		299 16 ·		105 35 ·	28
40	55 11		81 38	71 49		339 26		301 46		107 59	26
50	57 41		84 08	74 19		341 56		304 16		110 23	24
16 00	60 11	N10 56	86 38	76 49	N 2 34	344 27	N24 50	306 47	N16 43	112 48	S13 23
10	62 41		89 09	79 19		346 57		309 17		115 12	21
20	65 11		91 39	81 49		349 27		311 48		117 37	19
30	67 41 ·		94 10	84 19 ·		351 57 ·		314 18 ·		120 01 ·	17
40	70 11		96 40	86 49		354 27		316 48		122 26	16
50	72 41		99 10	89 19		356 57		319 19		124 50	14
17 00	75 11	N10 57	101 41	91 49	N 2 35	359 27	N24 50	321 49	N16 43	127 15	S13 12
10	77 41		104 11	94 19		1 58		324 20		129 39	10
20	80 11		106 42	96 49		4 28		326 50		132 04	09
30	82 41 ·		109 12	99 18 ·		6 58 ·		329 20 ·		134 28 ·	07
40	85 11		111 42	101 48		9 28		331 51		136 53	05
50	87 41		114 13	104 18		11 58		334 21		139 17	03
18 00	90 11	N10 58	116 43	106 48	N 2 36	14 29	N24 50	336 52	N16 43	141 41	S13 02
10	92 41		119 14	109 18		16 59		339 22		144 06	13 00
20	95 11		121 44	111 48		19 29		341 52		146 30	12 58
30	97 41 ·		124 15	114 18 ·		21 59 ·		344 23 ·		148 55 ·	56
40	100 11		126 45	116 48		24 29		346 53		151 19	55
50	102 41		129 15	119 18		26 59		349 24		153 44	53
19 00	105 11	N10 59	131 46	121 48	N 2 37	29 30	N24 49	351 54	N16 43	156 08	S12 51
10	107 41		134 16	124 18		32 00		354 24		158 33	49
20	110 11		136 47	126 48		34 30		356 55		160 57	48
30	112 41 ·		139 17	129 18 ·		37 00 ·		359 25 ·		163 22 ·	46
40	115 11		141 47	131 48		39 30		1 56		165 46	44
50	117 41		144 18	134 18		42 00		4 26		168 11	42
20 00	120 11	N11 00	146 48	136 48	N 2 39	44 31	N24 49	6 56	N16 43	170 35	S12 41
10	122 41		149 19	139 18		47 01		9 27		172 59	39
20	125 11		151 49	141 47		49 31		11 57		175 24	37
30	127 41 `		154 19	144 17 ·		52 01 ·		14 28 ·		177 48 ·	35
40	130 11		156 50	146 47		54 31		16 58		180 13	33
50	132 41		159 20	149 17		57 01		19 28		182 37	32
21 00	135 11	N11 01	161 51	151 47	N 2 40	59 32	N24 49	21 59	N16 43	185 02	S12 30
10	137 41		164 21	154 17		62 02		24 29		187 26	28
20	140 11		166 52	156 47		64 32		27 00		189 51	26
30	142 42 ·		169 22	159 17 ·		67 02 ·		29 30 ·		192 15 ·	25
40	145 12		171 52	161 47		69 32		32 00		194 40	23
50	147 42		174 23	164 17		72 02		34 31		197 04	21
22 00	150 12	N11 01	176 53	166 47	N 2 41	74 33	N24 49	37 01	N16 43	199 29	S12 19
10	152 42		179 24	169 17		77 03		39 32		201 53	17
20	155 12		181 54	171 47		79 33		42 02		204 18	15
30	157 42 ·		184 24	174 17 ·		82 03 ·		44 32 ·		206 42 ·	13
40	160 12		186 55	176 47		84 33		47 03		209 07	12
50	162 42		189 25	179 17		87 03		49 33		211 31	10
23 00	165 12	N11 02	191 56	181 46	N 2 42	89 34	N24 49	52 04	N16 43	213 56	S12 08
10	167 42		194 28	184 16		92 04		54 34		216 20	06
20	170 12		196 56	186 46		94 34		57 04		218 45	05
30	172 42 ·		199 27	189 16 ·		97 04 ·		59 35 ·		221 09 ·	03
40	175 12		201 57	191 46		99 34		62 05		223 34	12 01
50	177 42		204 28	194 16		102 04		64 36		225 58	11 59
24 00	180 12	N11 03	206 58	196 46	N 2 43	104 35	N24 49	67 06	N16 43	228 23	S11 57

Sunrise / Twilight / Moonrise

Lat	Sun rise	Twil	Moon rise	Diff
N o				
70	3 42	86	5 19	*
68	3 57	72	4 55	00
66	4 09	62	36	07
64	19	56	21	12
62	28	51	4 08	17
60	36	49	3 56	21
58	42	46	47	24
56	48	42	39	26
54	53	40	31	29
52	4 58	38	25	30
50	5 02	36	19	32
45	11	32	3 05	37
40	18	29	2 54	40
35	25	27	45	42
30	30	28	37	44
20	40	24	22	49
10	48	22	2 10	52
0	5 56	21	1 58	55
S 10	6 04	22	46	59
20	12	22	34	62
30	21	24	19	66
35	26	26	11	69
40	31	27	1 02	71
45	38	29	0 50	75
50	46	32	37	78
54	50	33	30	81
56	6 58	35	23	83
58	7 03	37	15	86
60	7 08	39	0 06	88
S		42	25 27	94

Sunset / Twilight / Moonset

Lat	Sun set	Twil	Moon set	Diff
N o				
70	20 20	87	11 21	125
68	20 04	73	11 44	114
66	19 52	63	12 01	108
64	41	57	16	102
62	33	52	28	97
60	25	48	38	93
58	18	43	47	89
56	12	41	12 55	86
54	07	39	13 02	84
52	19 02	36	07	82
50	18 58	34	13	80
45	49	31	25	76
40	41	29	35	72
35	35	27	44	69
30	29	25	13 51	67
20	19	23	14 04	62
10	11	22	14	59
0	18 03	21	24	56
S 10	17 55	22	35	51
20	47	23	46	47
30	38	24	14 58	44
35	33	28	15 05	40
40	27	28	13	38
45	21	30	22	34
50	13	33	33	30
52	09	34	38	28
54	05	36	44	26
56	17 01	38	15 51	24
58	16 55	40	15 57	22
60	16 50	42	16 05	18
S				

Sample page from "American Air Almanac."

GREENWICH A. M. 1944 APRIL 21 (FRIDAY)   223

GCT h m	☉ SUN GHA	Dec	♈ GHA	VENUS – ? GHA	Dec	MARS 1 5 GHA	Dec	JUPITER – 1 ● GHA	Dec	● MOON GHA	Dec	☾ Par
0 00	180 18	N11 45	208 56	196 29	N 3 41	105 22	N24 42	69 02	N16 42	202 25	S 2 02	
10	182 48		211 27	198 59		107 52		71 32		204 50	2 00	
20	185 18		213 57	201 29		110 22		74 03		207 14	1 58	
30	187 48 ·	·	216 28	203 58 ·	·	112 52 ·	·	76 33 ·		209 39 ·	55	
40	190 18		218 58	206 28		115 23		79 03		212 04	53	
50	192 48		221 28	208 58		117 53		81 34		214 28	51	
1 00	195 18	N11 45	223 59	211 28	N 3 43	120 23	N24 42	84 04	N16 41	216 53	S 1 49	
10	197 48		226 29	213 58		122 53		86 35		219 18	47	
20	200 18		229 00	216 28		125 23		89 05		221 42	44	
30	202 48 ·	·	231 30	218 58 ·	·	127 53 ·	·	91 35 ·		224 07 ·	42	
40	205 18		234 00	221 28		130 24		94 06		226 32	40	
50	207 48		236 31	223 58		132 54		96 36		228 57	38	
2 00	210 18	N11 46	239 01	226 28	N 3 44	135 24	N24 42	99 07	N16 41	231 21	S 1 36	
10	212 48		241 32	228 58		137 54		101 37		233 46	33	
20	215 18		244 02	231 28		140 24		104 07		236 11	31	
30	217 48 ·	·	246 33	233 58 ·		142 54 ·	·	106 38 ·		238 35 ·	29	
40	220 18		249 03	236 28		145 25		109 08		241 00	27	
50	222 48		251 33	238 58		147 55 ·		111 39		243 25	24	
3 00	225 19	N11 47	254 04	241 28	N 3 45	150 25	N24 41	114 09	N16 41	245 49	S 1 22	
10	227 49		256 34	243 57		152 55		116 39		248 14	20	
20	230 19		259 05	246 27		155 25		119 10		250 39	18	
30	232 49 ·	·	261 35	248 57 ·	·	157 55 ·	·	121 40 ·		253 03 ·	16	
40	235 19		264 05	251 27		160 25		124 11		255 28	13	
50	237 49		266 36	253 57		162 56		126 41		257 53	11	
4 00	240 19	N11 48	269 06	256 27	N 3 46	165 26	N24 41	129 11	N16 41	260 17	S 1 09	
10	242 49		271 37	258 57		167 56		131 42		262 42	07	
20	245 19		274 07	261 27		170 26		134 12		265 07	05	
30	247 49 ·	·	276 37	263 57 ·		172 56 ·	·	136 13 ·		267 31 ·	02	
40	250 19		279 08	266 27		175 26		139 13		269 56	1 00	
50	252 49		281 38	268 57		177 57		141 13		272 21	0 58	
5 00	255 19	N11 49	284 09	271 27	N 3 47	180 27	N24 41	144 11	N16 41	274 45	S 0 56	
10	257 49		286 39	273 57		182 57		146 11		277 10	53	
20	260 19		289 10	276 27		185 27		119 15		279 35	51	
30	262 49 ·	·	291 40	278 57 ·	·	187 57 ·	·	151 45 ·	·	281 59	49	
40	265 19		294 10	281 27		190 27		154 15		283 24	47	
50	267 49		296 41	283 56		192 58		156 16		286 49	45	
6 00	270 19	N11 50	299 11	286 26	N 3 49	195 28	N24 41	159 16	N16 41	289 13	S 0 42	
10	272 19		301 42	288 56		197 58		161 17		291 38	40	
20	275 19		304 12	291 26		200 28		164 17		294 03	38	
30	277 49 ·	·	306 42	293 56 ·		202 58 ·	·	166 47 ·		296 27 ·	36	
40	280 19		309 13	296 26		205 28		169 18		298 52	34	
50	282 49		311 43	298 56		207 59		171 18		301 17	31	
7 00	285 19	N11 50	314 11	301 26	N 3 50	210 29	N24 41	171 19	N16 41	303 42	S 0 29	
10	287 19		316 44	303 56		212 59		176 19		306 06	27	
20	290 19		319 14	306 26		215 29		179 19		308 31	25	
30	292 49 ·	·	321 45	308 56 ·		217 59 ·		181 50 ·		310 56 ·	22	
40	295 19		324 15	311 26		220 29		184 20		313 20	20	
50	297 49		326 46	313 56		223 00		186 51		315 45	18	
8 00	300 19	N11 51	329 16	316 26	N 3 51	225 30	N24 41	189 21	N16 41	318 10	S 0 16	
10	302 49		331 46	318 56		228 00		191 51		320 34	14	
20	305 19		334 17	321 26		230 30		191 22		322 59	11	
30	307 49 ·	·	336 47	323 55 ·		233 00 ·	·	196 52 ·		325 24 ·	09	
40	310 19		339 18	326 25		235 30		199 23		327 48	07	
50	312 49		341 48	328 55		238 01		201 53		330 13	05	
9 00	315 19	N11 52	344 19	331 25	N 3 52	240 31	N24 41	204 23	N16 41	332 38	S 0 03	
10	317 49		346 49	333 55		243 01		206 54		335 02	0 00	
20	320 19		349 19	336 25		245 31		209 24		337 27	N 0 02	
30	322 49 ·	·	351 50	338 55 ·		248 01 ·	·	211 55 ·		339 52	04	
40	325 19		354 20	341 25		250 31		214 25		342 17	06	
50	327 49		356 51	343 55		253 02		216 55		344 41	09	
10 00	330 19	N11 53	359 21	346 25	N 3 53	255 32	N24 40	219 26	N16 41	347 06	N 0 11	
10	332 49		1 51	348 55		258 02		221 56		349 31	13	
20	335 19		4 22	351 25		260 32		224 27		351 55	15	
30	337 49 ·	·	6 52	353 55 ·		263 02 ·	·	226 57 ·		354 20 ·	17	
40	340 20		9 23	356 25		265 32		229 27		356 45	20	
50	342 50		11 53	358 55		268 03		231 58		359 09	22	
11 00	345 20	N11 54	14 23	1 25	N 3 55	270 33	N24 40	234 28	N16 41	1 34	N 0 24	
10	347 50		16 54	3 54		273 03		236 59		3 59	26	
20	350 20		19 24	6 24		275 33		239 29		6 23	29	
30	352 50 ·	·	21 55	8 54 ·	·	278 03 ·		241 59 ·		8 48 ·	31	
40	355 20		24 25	11 24		280 33		244 30		11 13	33	
50	357 50		26 56	13 54		283 04		247 00		13 37	35	
12 00	0 20	N11 55	29 26	16 24	N 3 56	285 34	N24 40	249 31	N16 41	16 02	N 0 37	

Right-hand correction block:

° Alt	+ Corr
0	
8	60
13	59
17	58
22	57
25	56
27	55
29	54
31	53
32	52
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36	50
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62	30
63	29
64	28
65	27
67	26
69	25
70	24
71	23
72	22
73	21
74	20
75	19
76	18
77	17
78	16
79	15
80	14
	13
	12
	11
	10

SD ☉ 16

SD ☾ 16

Corr HA ☾

Int m 0 ... 10 0   Corr

East   Space   Regulus   JUPITER   MARS   SATURN   Aldebaran   MERCURY   VENUS   Arcturus   West

Sample page from "American Air Almanac."

.POLARIS

LHA ϒ	Corr.	LHA ϒ	Corr.	LHA ϒ	Corr.	LHA ϒ	Corr.	LHA ϒ	Corr.	LHA ϒ	Corr.
° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′
359 38	−54	89 40	−26	128 50	+14	179 11	+54	270 34	+26	309 49	−14
1 48	−55	90 44	−25	129 49	+15	181 23	+55	271 38	+25	310 48	−15
4 11	−56	91 46	−24	130 49	+16	183 48	+56	272 41	+24	311 47	−16
6 49	−57	92 49	−23	131 48	+17	186 29	+56	273 44	+23	312 46	−16
9 52	−58	93 50	−22	132 48	+18	189 38	+57	274 46	+22	313 45	−17
13 36	−59	94 52	−21	133 48	+19	192 22	+58	275 48	+21	314 45	−18
18 59	−59	95 53	−20	134 49	+19	198 51	+59	276 49	+20	315 46	−19
33 40	−60	96 53	−19	135 50	+21	213 48	+59	277 50	+19	316 46	−20
39 03	−59	97 54	−18	136 51	+22	219 17	+58	278 51	+18	317 47	−21
42 47	−58	98 54	−17	137 53	+23	223 01	+58	279 51	+17	318 49	−22
45 50	−57	99 53	−16	138 55	+23	226 10	+57	280 51	+17	319 50	−23
48 28	−56	100 52	−15	139 58	+24	228 51	+56	281 50	+16	320 53	−24
50 51	−55	101 51	−15	141 01	+25	231 16	+55	282 50	+15	321 55	−25
53 01	−54	102 50	−14	142 05	+26	233 28	+54	283 49	+14	322 59	−26
55 03	−53	103 49	−13	143 09	+27	235 32	+53	284 48	+13	324 03	−27
56 57	−52	104 47	−12	144 14	+28	237 27	+51	285 46	+12	325 07	−28
58 45	−51	105 45	−11	145 20	+29	239 17	+51	286 44	+11	326 12	−29
60 28	−50	106 43	−10	146 26	+30	241 01	+50	287 43	+10	327 18	−30
62 06	−49	107 41	− 9	147 34	+31	242 42	+49	288 41	+ 9	328 25	−31
63 41	−48	108 39	− 8	148 42	+32	244 18	+48	289 38	+ 8	329 32	−32
65 13	−47	109 37	− 7	149 51	+33	245 50	+47	290 36	+ 7	330 40	−33
66 41	−46	110 34	− 6	151 01	+34	247 20	+45	291 34	+ 6	331 50	−34
68 07	−45	111 32	− 5	152 12	+35	248 48	+45	292 31	+ 5	333 00	−35
69 31	−44	112 29	− 4	153 23	+36	250 12	+44	293 29	+ 4	334 11	−36
70 53	−43	113 26	− 3	154 37	+37	251 35	+42	294 26	+ 3	335 23	−37
72 12	−42	114 24	− 2	155 50	+38	252 56	+42	295 24	+ 2	336 37	−38
73 30	−41	115 21	− 1	157 07	+39	254 15	+41	296 21	+ 1	337 52	−39
74 47	−39	116 18	0	158 24	+40	255 32	+39	297 18	0	339 09	−40
76 02	−38	117 15	+ 1	159 43	+41	256 48	+39	298 15	− 1	349 27	−41
77 16	−37	118 13	+ 2	161 04	+42	258 02	+38	299 13	− 2	341 46	−42
78 28	−36	119 10	+ 3	162 27	+43	259 16	+37	300 10	− 3	343 08	−43
79 39	−35	120 08	+ 4	163 51	+44	260 27	+36	301 07	− 4	344 32	−44
80 49	−34	121 05	+ 5	165 19	+45	261 38	+35	302 05	− 5	345 58	−45
81 59	−33	122 03	+ 6	166 49	+46	262 48	+33	303 02	− 6	347 26	−46
83 07	−32	123 00	+ 7	168 21	+47	263 57	+33	304 00	− 7	348 58	−47
84 14	−31	123 58	+ 8	169 57	+48	265 05	+32	304 58	− 8	350 33	−48
85 21	−30	124 56	+ 9	171 38	+49	266 13	+31	305 56	− 9	352 11	−49
86 27	−29	125 55	+10	173 22	+50	267 19	+30	306 54	−10	353 54	−50
87 32	−28	126 53	+11	175 12	+51	268 25	+29	307 52	−11	355 42	−51
88 36	−27	127 51	+12	177 07	+52	269 30	+28	308 50	−12	357 36	−52
89 40		128 50	+13	179 11	+53	270 34	+27	309 49	−13	359 38	−53

LHA ϒ measured westward. Refraction not included. Use Table A.

STARS, CROSS REFERENCE

A. A. A.	B. A. A.	B. A. N. T	Astrograph
Achernar	. . . .	Achar	Achar
Adhara	Adara .		
Aldebaran		Aldeban	Aldeban
Alkaid	Benetnasch	. . (.	Beneah
Alnilam	Anilam	. . . .	. . . .
Alpheratz	. . . .	Alphaz	Alphaz
Arcturus		Arctus	
ε Argus	Avior	. . . .	. . . .
Betelgeux	Betelgeuse	Betelus	. . . .
δ Can. Maj.	Wezen	. . . .	. . . .
Deneb Kait.	Diphda	. . . .	. . . .
El Nath	Nath	. . . .	. . . .
Fomalhaut	. . . .	Fomalt	Fomalt
γ Gem.	Alhena	. . . .	. . . .
Marfak	Mirfak	. . . .	. . . .
Rasalague	Ras Alhague	. . . .	. . . .
Rigil Kent.	Rigel Kent.	Rikent	Rikent
Schedir	Schedar	. . . .	. . . .
ζ Orionis	Alnitak	. . . .	. . . .

ADDITIONAL STARS

Name	Mag.	SHA	Dec.
		° ′	° ′
Alkaid	1. 9	153 40	N49 35
γ Argus . . .	1. 9	238 03	S47 10
δ Can. Maj.. †	2 0	253 28	S26 18
Castor . .	1 6	247 15	N32 01
β Centauri . .	0. 9	150 02	S60 06
El Nath . . †	1. 8	279 19	N28 34
γ Gem. . . . †	1 9	261 23	N16 27
ζ Orionis . . †	1 9	275 31	S 1 58
Schedir. . .	2 1–2 6	350 41	N56 14

†The planetary section of the *Astronomical Navigation Tables* may be used for these stars.

Jan.–Apr., 1944

Sample page from "American Air Almanac."

STARS

Alphabetical order				Order of SHA			
Name	Mag.	SHA	Dec.	SHA	Dec	RA	Name
Acamar	3.4	315 58	S40 32	14 31	N14 54	23 02	Markab
Achernar . . . 1	0.6	336 06	S57 31	16 22	S29 55	22 55	Fomalhaut
Acrux . . . 2	1.1	174 07	S62 47	28 50	S47 14	22 05	Al Na'ir
Adhara . . . †	1.6	255 54	S28 54	34 39	N 9 37	21 41	Enif
Aldebaran . . .3	1.1	291 49	N16 24	50 07	N45 05	20 40	Deneb
Alioth	1 7	167 06	N56 16	54 42	S56 55	20 21	Peacock
Al Na'ir . . .	2.2	28 50	S47 14	62 59	N 8 43	19 48	Altair
Alnilam . . . †	1.8	276 39	S 1 14	77 03	S26 22	18 52	Nunki
Aiphard . . †	2 2	218 47	S 8 25	81 15	N38 44	18 35	Vega
Alphecca . †	2.3	126 55	N26 54	84 53	S34 25	18 20	Kaus Aust.
Alpherats 4	2.2	358 38	N28 47	91 11	N51 30	17 55	Etamin
Al Suhail	2.2	223 31	S43 12	96 55	N12 36	17 32	Rasalague
Altair 5	0.9	62 59	N 8 43	97 33	S37 04	17 30	Shaula
Antares . . 6	1.2	113 31	S26 18	103 13	S15 39	17 07	Sabik
Arcturus . . . 7	0.2	146 43	N19 28	(109 19)	S68 55	16 43	α Tri Aust.
Argus . . .	1 7	234 39	S59 20	113 31	S26 18	16 26	Antares
Bellatrix . . . †	1.7	279 28	N 6 18	120 45	S22 28	15 57	Dschubba
Betelgeux . . 8	0.1-1.2	271 58	N 7 24	126 55	N26 54	15 32	Alphecca
Canopus . . . 9	−0.9	264 19	S52 40	(137 17)	N74 23	14 51	Kochab
Capella . . . 10	0.2	281 52	N45 57	141 03	S60 36	14 36	Rigil Kent.
Caph	2 4	358 28	N58 50	146 43	N19 28	14 13	Arcturus
θ Centauri	2 3	149 09	S36 06	149 09	S36 06	14 03	θ Centauri
β Crucis	1 5	168 53	S59 23	159 26	S10 52	13 22	Spica
γ Crucis	1 6	172 59	S56 48	159 35	N55 13	13 22	Mizar
Deneb 11	1.3	50 07	N45 05	167 06	N56 16	12 52	Alioth
Deneb Kait. . †	2 2	349 49	S18 18	168 53	S59 23	12 44	β Crucis
Denebola. . . †	2 2	183 27	N14 53	172 59	S56 48	12 28	γ Crucis
Dschubba . .	2.5	120 45	S22 28	174 07	S62 47	12 24	Acrux
Dubhe . . 12	2 0	194 55	N62 03	183 27	N14 53	11 46	Denebola
Enif	2.5	34 39	N 9 37	194 55	N62 03	11 00	Dubhe
Etamin . .	2 4	91 11	N51 30	208 39	N12 14	10 05	Regulus
Fomalhaut . 13	1.3	16 22	S29 55	218 47	S 8 25	9 25	Alphard
Hamal . . .†	2 2	329 00	N23 12	(221 50)	S69 29	9 13	Miaplacidus
Kaus Aust. .	2 0	84 53	S34 25	223 31	S43 12	9 06	Al Suhail
Kochab	2.2	(137 17)	N74 23	234 39	S59 20	8 21	Argus
Marfak	1 9	309 55	N49 40	244 32	N28 10	7 42	Pollux
Markab	2 6	14 31	N14 54	245 54	N 5 22	7 36	Procyon
Miaplacidus . . .	1 8	(221 50)	S69 29	255 54	S28 54	6 56	Adhara
Mizar	2 4	159 35	N55 13	259 20	S16 39	6 43	Sirius
Nunki	2 1	77 03	S26 22	264 19	S52 40	6 23	Canopus
Peacock . . . 14	2 1	54 42	S56 55	271 58	N 7 24	5 52	Betelgeux
Polaris	2.1	(333 51)	N89 00	276 39	S 1 14	5 33	Alnilam
Pollux 15	1.2	244 32	N28 10	279 28	N 6 18	5 22	Bellatrix
Procyon . . . 16	0.5	245 54	N 5 22	281 52	N45 57	5 13	Capella
Rasalague . . . †	2.1	96 55	N12 36	282 02	S 8 16	5 12	Rigel
Regulus . . . 17	1.3	208 39	N12 14	291 49	N16 24	4 33	Aldebaran
Rigel 18	0.3	282 02	S 8 16	309 55	N49 40	3 20	Marfak
Rigil Kent. . . 19	0.3	141 03	S60 36	315 58	S40 32	2 56	Acamar
Ruchbah	2 8	339 28	N59 57	329 00	N23 12	2 04	Hamal
Sabik	2.6	103 13	S15 39	(333 51)	N89 00	1 45	Polaris
Shaula	1.7	97 33	S37 04	336 06	S57 31	1 36	Achernar
Sirius . . . 20	1.6	259 20	S16 39	339 28	N59 57	1 22	Ruchbah
Spica . . . 21	1.2	159 26	S10 52	349 49	S18 18	0 41	Deneb Kait.
α Tri. Aust. . .	1.9	(109 19)	S68 55	358 28	N58 50	0 06	Caph
Vega 22	0.1	81 15	N38 44	358 38	N28 47	0 05	Alpherats

SHA=360°−RA   GHA*=GHA♈+SHA*

Sample page from "H O. 211 (Ageton)."

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

	15° 00'		15° 30'		16° 00'		16° 30'		17° 00'		
'	A	B	A	B	A	B	A	B	A	B	'
0	58700	1506	57310	1609	55966	1716	54666	1826	53406	1940	30
	58677	1507	57287	1611	55944	1718	54644	1828	53386	1942	
1	58653	1509	57265	1612	55922	1719	54623	1830	53365	1944	29
	58630	1511	57242	1614	55900	1721	54602	1832	53344	1946	
2	58606	1512	57219	1616	55878	1723	54581	1834	53324	1948	28
	58583	1514	57196	1618	55856	1725	54559	1836	53303	1950	
3	58559	1516	57174	1619	55834	1727	54538	1837	53283	1952	27
	58536	1517	57151	1621	55812	1728	54517	1839	53262	1954	
4	58512	1519	57128	1623	55790	1730	54496	1841	53241	1956	26
	58489	1521	57106	1625	55768	1732	54474	1843	53221	1958	
5	58465	1523	57083	1627	55746	1734	54453	1845	53200	1960	25
	58442	1524	57060	1628	55725	1736	54432	1847	53180	1962	
6	58418	1526	57038	1630	55703	1738	54411	1849	53159	1964	24
	58395	1528	57015	1632	55681	1739	54390	1851	53139	1966	
7	58372	1529	56992	1634	55659	1741	54368	1853	53118	1967	23
	58348	1531	56970	1635	55637	1743	54347	1854	53098	1969	
8	58325	1533	56947	1637	55615	1745	54326	1856	53077	1971	22
	58302	1534	56925	1639	55593	1747	54305	1858	53057	1973	
9	58278	1536	56902	1641	55572	1749	54284	1860	53036	1975	21
	58255	1538	56880	1642	55550	1750	54263	1862	53016	1977	
10	58232	1540	56857	1644	55528	1752	54242	1864	52995	1979	20
	58208	1541	56835	1646	55506	1754	54220	1866	52975	1981	
11	58185	1543	56812	1648	55484	1756	54199	1868	52954	1983	19
	58162	1545	56790	1649	55463	1758	54178	1870	52934	1985	
12	58138	1546	56767	1651	55441	1760	54157	1871	52914	1987	18
	58115	1548	56745	1653	55419	1761	54136	1873	52893	1989	
13	58092	1550	56722	1655	55397	1763	54115	1875	52873	1991	17
	58069	1552	56700	1657	55376	1765	54094	1877	52852	1993	
14	58046	1553	56677	1658	55354	1767	54073	1879	52832	1995	16
	58022	1555	56655	1660	55332	1769	54052	1881	52812	1997	
15	57999	1557	56632	1662	55311	1771	54031	1883	52791	1999	15
	57976	1559	56610	1664	55289	1772	54010	1885	52771	2001	
16	57953	1560	56588	1665	55267	1774	53989	1887	52751	2003	14
	57930	1562	56565	1667	55246	1776	53968	1889	52730	2005	
17	57907	1564	56543	1669	55224	1778	53947	1890	52710	2007	13
	57884	1565	56521	1671	55202	1780	53926	1892	52690	2009	
18	57860	1567	56498	1673	55181	1782	53905	1894	52670	2010	12
	57837	1569	56476	1674	55159	1783	53884	1896	52649	2012	
19	57814	1571	56454	1676	55138	1785	53864	1898	52629	2014	11
	57791	1572	56431	1678	55116	1787	53843	1900	52609	2016	
20	57768	1574	56409	1680	55095	1789	53822	1902	52588	2018	10
	57745	1576	56387	1682	55073	1791	53801	1904	52568	2020	
21	57722	1578	56365	1683	55051	1793	53780	1906	52548	2022	9
	57699	1579	56342	1685	55030	1795	53759	1908	52528	2024	
22	57676	1581	56320	1687	55008	1796	53738	1910	52508	2026	8
	57653	1583	56298	1689	54987	1798	53718	1911	52487	2028	
23	57630	1584	56276	1691	54965	1800	53697	1913	52467	2030	7
	57607	1586	56254	1692	54944	1802	53676	1915	52447	2032	
24	57584	1588	56231	1694	54922	1804	53655	1917	52427	2034	6
	57561	1590	56209	1696	54901	1806	53634	1919	52407	2036	
25	57538	1591	56187	1698	54880	1808	53614	1921	52387	2038	5
	57516	1593	56165	1700	54858	1809	53593	1923	52366	2040	
26	57493	1595	56143	1701	54837	1811	53572	1925	52346	2042	4
	57470	1597	56121	1703	54815	1813	53551	1927	52326	2044	
27	57447	1598	56099	1705	54794	1815	53531	1929	52306	2046	3
	57424	1600	56076	1707	54773	1817	53510	1931	52286	2048	
28	57401	1602	56054	1709	54751	1819	53489	1933	52266	2050	2
	57378	1604	56032	1710	54730	1821	53468	1935	52246	2052	
29	57356	1605	56010	1712	54708	1823	53448	1936	52226	2054	1
	57333	1607	55988	1714	54687	1824	53427	1938	52206	2056	
30	57310	1609	55966	1716	54666	1826	53406	1940	52186	2058	0
	A	B	A	B	A	B	A	B	A	B	'
	164° 30'		164° 00'		163° 30'		163° 00'		162° 30'		

Sample page from "H O 211 (Ageton)."

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	30° 00′ A	30° 00′ B	30° 30′ A	30° 30′ B	31° 00′ A	31° 00′ B	31° 30′ A	31° 30′ B	32° 00′ A	32° 00′ B	′
0	30103	6247	29453	6468	28816	6693	28191	6923	27579	7158	30
	30092	6251	29442	6472	28806	6697	28181	6927	27569	7162	
1	30081	6254	29432	6475	28795	6701	28171	6931	27559	7166	29
	30070	6258	29421	6479	28785	6705	28161	6935	27549	7170	
2	30059	6262	29410	6483	28774	6709	28150	6939	27539	7174	28
	30048	6265	29399	6487	28763	6712	28140	6943	27528	7178	
3	30037	6269	29389	6490	28753	6716	28130	6947	27518	7182	27
	30026	6273	29378	6494	28743	6720	28119	6951	27508	7186	
4	30016	6276	29367	6498	28732	6724	28109	6954	27498	7190	26
	30005	6280	29357	6501	28722	6728	28099	6958	27488	7193	
5	29994	6284	29346	6505	28711	6731	28089	6962	27478	7197	25
	29983	6287	29335	6509	28701	6735	28078	6966	27468	7201	
6	29972	6291	29325	6513	28690	6739	28068	6970	27458	7205	24
	29961	6294	29314	6516	28680	6743	28058	6974	27448	7209	
7	29950	6298	29303	6520	28669	6747	28047	6978	27438	7213	23
	29939	6302	29293	6524	28659	6750	28037	6982	27428	7217	
8	29928	6305	29282	6528	28648	6754	28027	6985	27418	7221	22
	29917	6309	29271	6531	28638	6758	28017	6989	27408	7225	
9	29907	6313	29261	6535	28627	6762	28006	6993	27398	7229	21
	29896	6316	29250	6539	28617	6766	27996	6997	27387	7233	
10	29885	6320	29239	6543	28606	6770	27986	7001	27377	7237	20
	29874	6324	29229	6546	28596	6773	27976	7005	27367	7241	
11	29863	6328	29218	6550	28586	6777	27965	7009	27357	7245	19
	29852	6331	29207	6554	28575	6781	27955	7013	27347	7249	
12	29841	6335	29197	6558	28565	6785	27945	7017	27337	7253	18
	29831	6339	29186	6561	28554	6789	27935	7021	27327	7257	
13	29820	6342	29175	6565	28544	6793	27925	7024	27317	7261	17
	29809	6346	29165	6569	28533	6796	27914	7028	27307	7265	
14	29798	6350	29154	6573	28523	6800	27904	7032	27297	7269	16
	29787	6353	29144	6576	28513	6804	27894	7036	27287	7273	
15	29776	6357	29133	6580	28502	6808	27884	7040	27277	7277	15
	29766	6361	29122	6584	28492	6812	27874	7044	27267	7281	
16	29755	6364	29112	6588	28481	6815	27863	7048	27257	7285	14
	29744	6368	29101	6591	28471	6819	27853	7052	27247	7289	
17	29733	6372	29091	6595	28461	6823	27843	7056	27237	7293	13
	29722	6375	29080	6599	28450	6827	27833	7060	27227	7297	
18	29711	6379	29069	6603	28440	6831	27823	7064	27217	7301	12
	29701	6383	29059	6606	28429	6835	27812	7067	27207	7305	
19	29690	6386	29048	6610	28419	6839	27802	7071	27197	7309	11
	29679	6390	29038	6614	28409	6842	27792	7075	27187	7313	
20	29668	6394	29027	6618	28398	6846	27782	7079	27177	7317	10
	29657	6398	29016	6622	28388	6850	27772	7083	27167	7321	
21	29647	6401	29006	6625	28378	6854	27761	7087	27157	7325	9
	29636	6405	28995	6629	28367	6858	27751	7091	27147	7329	
22	29625	6409	28985	6633	28357	6862	27741	7095	27137	7333	8
	29614	6412	28974	6637	28346	6865	27731	7099	27127	7337	
23	29604	6416	28964	6640	28336	6869	27721	7103	27117	7341	7
	29593	6420	28953	6644	28326	6873	27711	7107	27107	7345	
24	29582	6423	28942	6648	28315	6877	27701	7111	27098	7349	6
	29571	6427	28932	6652	28305	6881	27690	7115	27088	7353	
25	29560	6431	28921	6655	28295	6885	27680	7118	27078	7357	5
	29550	6435	28911	6659	28284	6889	27670	7122	27068	7361	
26	29539	6438	28900	6663	28274	6893	27660	7126	27058	7365	4
	29528	6442	28890	6667	28264	6896	27650	7130	27048	7369	
27	29517	6446	28879	6671	28253	6900	27640	7134	27038	7373	3
	29507	6449	28869	6674	28243	6904	27630	7138	27028	7377	
28	29496	6453	28858	6678	28233	6908	27619	7142	27018	7381	2
	29485	6457	28848	6682	28222	6912	27609	7146	27008	7385	
29	29475	6461	28837	6686	28212	6916	27599	7150	26998	7389	1
	29464	6464	28827	6690	28202	6920	27589	7154	26988	7393	
30	29453	6468	28816	6693	28191	6923	27579	7158	26978	7397	0
′	A	B	A	B	A	B	A	B	A	B	′
	149° 30′		149° 00′		148° 30′		148° 00′		147° 30′		

Sample page from "H.O. 214."

DECLINATION SAME NAME AS LATITUDE

Lat. 43° — 90

H.A.	20° 00' Alt	Δd Δt	Az	20° 30' Alt	Δd Δt	Az	21° 00' Alt	Δd Δt	Az	21° 30' Alt	Δd Δt	Az	22° 00' Alt	Δd Δt	Az	22° 30' Alt	Δd Δt
00	67 00.0	1.0 02	180.0	67 30.9	1.0 02	180.0	68 00.0	1.0 02	180.0	68 30.0	1.0 02	180.0	69 00.0	1.0 02	180.0	69 30.0	1.0 02
1	66 59.1	1.0 05	177.6	67 29.1	1.0 05	177.6	67 59.0	1.0 05	177.5	68 29.0	1.0 05	177.5	68 59.0	1.0 05	177.4	69 29.9	1.0 05
2	66 56.3	1.0 08	175.1	67 26.3	1.0 08	175.1	67 56.2	1.0 08	175.0	68 26.1	1.0 08	174.9	68 56.0	1.0 08	174.8	69 26.0	1.0 08
3	66 51.7	0 11	172.8	67 21.6	0 11	172.7	67 51.4	99 11	172.6	68 21.3	99 11	172.4	68 51.1	99 11	172.3	69 20.9	99 12
4	66 45.3	99 14	170.4	67 15.1	99 14	170.3	67 44.8	99 14	170.1	68 14.2	99 15	169.7				69 13.9	00 15
05	66 37.2	99 17	168.1	67 06.8	99 17	167.9	67 36.4	99 17	167.7	68 05.9	99 17	167.4	68 35.5	98 18	167.2	69 05.0	98 18
6	66 27.2	98 19	165 8	66 56.7	98 20	165.5	67 26.1	98 20	165.3	67 55.5	98 20	165.0	68 24.8	98 21	164.7	68 54.2	98 21
7	66 15.6	98 22	163.5	66 44.8	97 22	163.2	67 14.1	97 23	162.9	67 43.2	97 23	162.6	68 12.4	97 24	162.3	68 41.5	97 24
8	66 02.3	97 25	161.2	66 31.3	97 25	160.9	67 00.3	97 26	160.6	67 29.2	96 26	160.2	67 58.1	96 27	159.9	68 27.0	96 27
9	65 47.4	96 28	159 0	66 16.1	96 28	158.6	66 44.9	96 28	158.3	67 13.6	96 29	157.9	67 42.2	96 29	157 5	68 10.8	96 30
10	65 30.9	95 30	156 8	65 59.4	96 30	156.4	66 27.9	96 31	156.0	66 56.3	96 31	155.6	67 24.6	94 32	155.2	67 52.9	94 32
1	65 12.8	94 32	154.7	65 41.1	94 33	154 3	66 09.3	94 33	153.9	66 37.4	94 34	153 4	67 05.4	94 34	153 0	67 33.4	93 35
2	64 53.3	93 35	152.6	65 21.3	93 35	152 2	65 49.2	93 36	151.7	66 17.0	93 36	151.3	66 44.7	93 37	150 8	67 12.4	93 37
3	64 32.4	92 37	150 5	65 00.1	92 38	150 1	65 27.7	92 38	149.6	65 55.2	92 39	149.1	66 22.6	91 39	148 8	66 49.9	91 40
4	64 10.2	91 39	148 5	64 37.6	91 40	148.1	65 04.8	91 40	147.6	65 32.0	90 41	147.1	65 59.1	90 41	146 6	66 26.0	00 42
15	63 46.7	90 41	146 6	64 13.7	90 42	146.1	64 40.7	90 42	145.6	65 07.5	89 43	145.1	65 34.3	89 43	144 5	66 00.9	88 44
6	63 21.9	89 43	144.7	63 48.7	89 44	144.2	64 15.3	89 44	143.7	64 41.8	88 45	143.1	65 08.2	88 45	142.6	65 34.4	87 46
7	62 56.6	88 45	142.9	63 22.4	88 46	142.3	63 48.7	87 46	141.8	64 14.9	87 47	141.2	64 40.9	87 47	140 7	65 06.8	86 48
8	62 28.9	87 47	141.1	62 55.0	87 47	140 5	63 21.0	86 48	140.0	63 46.5	85 49	139 4	64 12.6	86 49	138 8	64 38.1	85 50
9	62 00.5	86 48	139.3	62 26.6	86 49	138 8	62 52.3	85 50	138 2	63 17.5	85 50	137.6	63 43.2	84 51	137 0	64 08.4	84 51
20	61 31 7	85 50	137.6	61 57.2	85 51	137.1	62 22.5	84 51	136 5	62 47.7	84 52	135.0	63 12.8	83 52	135 3	63 37.6	83 53
1	61 01.7	84 52	136 0	61 26.8	84 52	135 4	61 51.9	83 53	134 8	62 16.7	83 53	134.2	62 41.4	82 54	133 6	63 06.0	82 54
2	60 30.7	83 53	134.3	60 55.6	83 54	133.8	61 20.3	82 54	133.2	61 44.8	82 55	132.6	62 09.2	81 55	132 0	62 33.4	80 55
3	59 58.9	82 54	132 8	60 23.5	82 56	132.2	60 47.9	81 56	131.6	61 12.1	81 56	131 0	61 36.2	80 56	130.4	62 00.1	79 57
4	59 26.3	81 56	131.3	59 50.6	81 56	130 7	60 14.7	80 57	130 1	60 38.6	79 57	129 5	61 02.4	79 58	128.8	61 26.0	78 58
25	58 53.0	80 57	129.8	59 17.0	80 57	129.2	59 40.8	79 58	128.6	60 04.4	78 58	128 0	60 27.9	78 59	127.4	60 51.1	77 59
6	58 18.9	79 58	128.3	58 42.6	79 58	127.8	59 06.1	78 59	127.2	59 29.5	78 59	126 5	59 52.6	77 60	125 9	60 15.6	76 60
7	57 44.2	78 59	126 9	58 07.6	78 60	126.4	58 30.8	77 60	125.8	58 53.9	77 61	125.1	59 16.8	76 61	124 5	59 39.5	75 61
8	57 08.8	77 60	125.6	57 31.9	77 60	125.0	57 54.9	76 61	124.4	58 17.7	76 61	123.8	58 40.3	75 62	123 2	59 02.8	74 62
9	56 32.8	77 61	124 3	56 55.7	76 61	123 7	57 18.4	75 62	123.1	57 41.0	75 62	122 5	58 03.3	74 63	121 8	58 25.5	74 63
30	55 56.3	76 62	123.0	56 18.9	75 62	122.4	56 41.4	75 63	121.8	57 03.7	74 63	121 2	57 25.8	73 63	120 6	57 47.7	73 64
1	55 19.2	75 63	121 7	55 41.6	74 63	121.1	56 03.8	74 64	120.5	56 25.9	73 64	119.9	56 47.8	73 64	119 3	57 09.4	72 65
2	54 41.6	74 63	120 5	55 03.8	74 64	119.9	55 25.8	73 64	119.3	55 47.6	72 65	118.7	56 09.3	72 65	118.1	56 30.7	71 65
3	54 03.6	73 64	119.3	54 25.5	73 64	118 7	54 47.3	72 65	118.1	55 08.9	72 65	117.5	55 30.3	71 66	116.9	55 51.6	70 66
4	53 25.1	73 65	118 2	53 46.9	72 65	117.6	54 08.4	73 06	117 0	54 29.8	71 66	116 4	54 51.0	70 66	115 8	55 12.0	70 66
35	52 46.2	72 65	117.0	53 07.8	72 66	116 4	53 29.3	71 66	115 9	53 50.5	70 67	115.3	54 11.3	70 67	114 6	54 32.1	69 67
6	52 06.9	71 66	115.9	52 28.3	71 66	115 3	52 49.4	70 57	114.8	53 10.4	70 67	114 2	53 31.3	69 67	113 6	53 51.9	68 68
7	51 27.3	71 67	114 8	51 48.4	70 67	114.3	52 09.4	70 67	113.7	52 30.2	69 68	113.1	52 50.9	68 68	112.5	53 11.3	68 68
8	50 47.3	70 67	113 8	51 08.3	70 67	113 2	51 29.1	69 68	112.6	51 49.7	68 68	112.0	52 10.2	68 68	111 5	52 30.5	67 69
9	50 07.0	70 68	112.7	50 27.8	69 68	112 2	50 48.4	69 68	111.6	51 08.9	68 68	111.0	51 29.2	67 69	110 4	51 49.3	67 69
40	49 26.4	69 68	111 7	49 47.0	69 69	111.2	50 07.5	69 69	110.6	50 27.8	67 69	110.0	50 48.0	67 69	109.4	51 07.9	66 69
1	48 45.5	69 69	110.7	49 06.0	68 69	110 2	49 26.3	67 69	109.6	49 46.5	67 69	109.1	50 06.4	66 70	108 5	50 26.3	66 70
2	48 04.3	68 69	109 8	48 24.7	68 69	109.2	48 44.8	67 69	108 7	49 04.9	66 70	108.1	49 24.7	66 70	107.5	49 44.4	66 70
3	47 22.9	68 69	108 8	47 43.1	67 70	108.3	48 03.2	67 70	107.7	48 23.1	66 70	107.2	48 42.8	65 70	106 6	49 02.3	65 70
4	46 41.2	67 70	107.9	47 01.3	67 70	107.4	47 21.2	66 70	106 8	47 41.0	66 70	106 3	48 00.6	65 71	105 7	48 20.1	65 71
45	45 59.4	67 70	107 0	46 19.3	66 70	106.5	46 39.1	66 70	105 9	46 58.8	65 71	105.4	47 18.3	65 71	104 8	47 37.6	64 71
6	45 17.3	66 70	106.1	45 37.2	66 71	105.6	45 56.9	65 71	105.0	46 16.4	65 71	104.5	46 35.8	64 71	103 9	46 55.0	64 71
7	44 35.1	66 71	105 2	44 54.8	66 71	104.7	45 14.4	65 71	104.2	45 33.8	64 71	103.6	45 53.1	64 71	103 1	46 12.2	63 72
8	43 52.6	66 71	104.4	44 12.3	65 71	103 8	44 31.8	65 71	103 3	44 51.1	64 72	102 8	45 10.3	64 72	102 2	45 29.3	63 72
9	43 10.0	66 71	103 5	43 29.8	65 71	103 0	43 49.0	64 72	102.5	44 08.2	64 72	101.9	44 27.3	63 72	101 4	44 46.3	63 72
50	42 27.3	65 71	102.7	42 46.8	65 72	102 2	43 06.1	64 72	101.6	43 25.2	64 72	101.1	43 44.2	63 72	100 6	44 03.1	63 72
1	41 44.4	65 72	101.8	42 03.8	64 72	101.3	42 23.0	64 72	100.8	42 42.1	63 72	100.3	43 01.1	63 72	99.8	43 19.9	62 72
2	41 01.4	65 72	101.0	41 20.7	64 72	100.5	41 39.9	64 72	100.0	41 58.9	63 72	99.5	42 17.8	63 72	99.0	42 36.5	62 73
3	40 18.3	64 72	100.2	40 37.5	64 72	99.7	40 56.6	63 72	99.2	41 15.6	63 72	98.7	41 34.4	62 72	98.2	41 53.0	62 73
4	39 35.1	64 72	99 5	39 54.2	64 72	99 0	40 13.2	63 72	98 4	40 32.1	63 72	97.9	40 50.9	62 73	97.4	41 09.5	62 73
55	38 51.7	64 73	98.7	39 10.8	63 72	98 2	39 29.8	63 73	97.7	39 48.8	63 73	97.2	40 07.3	62 73	96.7	40 25.9	62 73
6	38 08.3	64 72	97.9	38 27.3	63 73	97 4	38 46.3	63 73	96.9	39 05.1	62 73	96 4	39 23.7	62 73	95 9	39 42.3	62 73
7	37 24.8	64 73	97.2	37 43.8	63 73	96.7	38 02.7	63 73	96.2	38 21.4	62 73	95.7	38 40.1	62 73	95 2	38 58.6	61 73
8	36 41.2	63 73	96.4	37 00.2	63 73	95 9	37 19.0	63 73	95.4	37 37.7	62 73	94 9	37 56.3	62 73	94 4	38 14.8	61 73
9	35 57.6	63 73	95.7	36 16.5	63 73	95 2	36 35.3	62 73	94.7	36 54.0	62 73	94.2	37 12.6	62 73	93 7	37 31.0	61 73
60	35 13.9	63 73	94.9	35 32.8	63 73	94.5	35 51.6	62 73	94 0	36 10.2	62 73	93.5	36 28.8	62 73	93 0	36 47.2	61 73
1	34 30.1	63 73	94.2	34 49.9	63 73	93.7	35 07.8	62 73	93.3	35 26.4	62 73	92 8	35 44.9	62 73	92 3	36 03.3	61 73
2	33 46.4	63 73	93.5	34 05.2	63 73	93 0	34 23.9	62 73	92.6	34 42.6	62 73	92.1	35 01.5	51 73	91.6	35 19.5	61 73
3	33 02.8	63 73	92 8	33 21.4	63 73	92 3	33 40.1	62 73	91.9	33 58.7	62 73	91.4	34 17.2	51 73	90 9	34 35.6	61 73
4	32 18.7	63 73	92.1	32 37.5	63 73	91 6	32 56.2	62 73	91.2	33 14.8	62 73	90 7	33 33.3	51 73	90 2	33 51.7	61 73
65	31 34.8	63 73	91 4	31 53.6	63 73	90.9	32 12.3	62 73	90.6	32 30.9	62 73	90.0	32 49.4	61 73	89 5	33 07.8	61 73
6	30 51.0	63 73	90.7	31 09.8	62 73	90 2	31 28.5	62 73	89 8	31 47.1	62 73	89 3	32 05.6	61 73	88 9	32 23.9	61 73
7	30 07.1	63 73	90 0	30 25.9	62 73	89 6	30 44.5	62 73	89 1	31 03.2	62 73	88.7	31 21.7	62 73	88 2	31 40.1	61 73
8	29 23.2	63 73	89 3	29 42.0	62 73	88 9	30 00.7	62 73	88.4	30 19.3	62 73	88.0	30 37.8	62 73	87 5	30 56.3	51 73
9	28 39.3	63 73	88 7	28 58.1	62 73	88 2	29 16.9	52 73	87 8	29 35 5	62 73	87.3	29 54 0	62 73	86 9	30 12.4	61 73
70	27 55.5	63 73	88 0	28 14.3	62 73	87.6	28 33.0	62 73	87.1	28 51.7	62 73	86.7	29 10.2	62 73	86.2	29 28.7	61 73
1	27 11.6	62 73	87.3	27 30.5	62 73	86 9	27 49.2	62 73	86.4	28 07.9	62 73	86.0	28 26.4	62 73	85 6	28 44.9	61 73
2	26 27.8	63 73	86.7	26 46.7	62 73	86.2	27 05.4	62 73	85.8	27 24.1	62 73	85.4	27 42.7	62 73	84.9	28 01.2	61 73

Sample page from "H.O. 218."

7   NORTH LATITUDES   ARCTURUS

LAT.	30°		31°		32°		33°		34°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
0	79 30−19	180	78 30−19	180	77 30−19	180	76 30−19	180	75 30+19	180	360
1	79 27 19	175	78 28 19	175	77 28 19	176	76 28 19	176	75 28 19	176	359
2	79 20 18	170	78 21 18	171	77 22 19	171	76 23 19	172	75 23 19	173	358
3	79 09 18	165	78 11 18	166	77 12 18	167	76 14 18	168	75 15 18	169	357
4	78 53 18	160	77 57 18	162	76 59 18	163	76 02 18	164	75 04 18	165	356
5	78 34−17	156	77 39−18	157	76 43−18	159	75 47−18	160	74 50−18	162	355
6	78 10 17	151	77 17 17	153	76 23 17	155	75 28 18	157	74 33 18	158	354
7	77 44 16	147	76 53 17	150	76 00 17	152	75 07 17	153	74 13 17	155	353
8	77 14 16	144	76 25 16	146	75 35 16	148	74 43 17	150	73 51 17	152	352
9	76 42 15	140	75 55 16	143	75 07 16	145	74 17 16	147	73 26 17	149	351
10	76 08−15	137	75 23−15	140	74 37−16	142	73 49−16	144	72 59−16	146	350
11	75 31 14	134	74 49 15	137	74 04 15	139	73 18 16	141	72 31 16	143	349
12	74 53 14	131	74 12 14	134	73 30 15	136	72 46 15	139	72 00 16	141	348
13	74 13 13	129	73 35 14	131	72 54 14	134	72 12 15	136	71 28 15	138	347
14	73 32 13	126	72 55 13	129	72 17 14	131	71 36 14	134	70 54 15	136	346
15	72 50−12	124	72 15−13	127	71 38−13	129	70 59−14	132	70 18−14	134	345
16	72 06 12	122	71 33 12	125	70 58 13	127	70 21 14	129	69 42 14	132	344
17	71 22 11	120	70 50 12	123	70 17 13	125	69 41 13	127	69 04 14	130	343
18	70 37 11	119	70 07 12	121	69 35 12	123	69 01 13	126	68 25 13	128	342
19	69 51 11	117	69 22 11	119	68 52 12	122	68 20 13	124	67 45 13	126	341
20	69 04−10	116	68 37−11	118	68 08−12	120	67 37−12	122	67 05−13	124	340
21	68 17 10	114	67 52 11	116	67 24 11	118	66 54 12	121	66 23 13	123	339
22	67 29 10	113	67 05 11	115	66 39 11	117	66 11 12	119	65 41 12	121	338
23	66 41 10	111	66 18 10	114	65 53 11	116	65 26 12	118	64 58 12	120	337
24	65 53 9	110	65 31 10	112	65 07 11	114	64 42 11	116	64 14 12	118	336
25	65 04−9	109	64 43−10	111	64 21−10	113	63 56−11	115	63 30−12	117	335
26	64 15 9	108	63 55 10	110	63 34 10	112	63 10 11	114	62 45 11	116	334
27	63 25 9	107	63 07 10	109	62 46 10	111	62 24 11	113	62 00 11	114	333
28	62 35 9	106	62 18 9	108	61 59 10	110	61 37 10	111	61 15 11	113	332
29	61 45 9	105	61 29 9	107	61 10 10	109	60 50 10.	110	60 29 11	112	331
30	60 55−9	104	60 39−9	106	60 22−10	108	60 03−10	109	59 43−11	111	330
31	60 05 8	103	59 50 9	105	59 34 9	107	59 16 10	108	58 56 11	110	329
32	59 14 8	102	59 00 9	104	58 45 9	106	58 28 10	107	58 09 10	109	328
33	58 23 8	102	58 10 9	103	57 56 9	105	57 39 10	106	57 22 10	108	327
34	57 32 8	101	57 20 9	102	57 06 9	104	56 51 10	105	56 34 10	107	326
35	56 41 −8	100	56 30 −9	102	56 17 −9	103	56 03−10	105	55 47−10	106	325
36	55 50 8	99	55 39 8	101	55 27 9	102	55 14 9	104	54 59 10	105	324
37	54 59 8	99	54 49 8	100	54 38 9	102	54 25 9	103	54 11 10	104	323
38	54 07 8	98	53 58 8	99	53 48 9	101	53 36 9	102	53 22 10	103	322
39	53 16 8	97	53 07 8	99	52 58 9	100	52 46 9	101	52 34 10	103	321
40	52 24 −8	97	52 17 −8	98	52 07 −9	99	51 57 −9	101	51 45−10	102	320
41	51 33 8	96	51 26 8	97	51 17 9	99	51 08 9	100	50 57 9	101	319
42	50 41 8	96	50 35 8	97	50 27 8	98	50 18 9	99	50 08 9	100	318
43	49 49 8	95	49 43 8	96	49 28 8	97	49 28 9	98	49 19 9	100	317
44	48 58 8	94	48 52 8	96	48 46 8	97	48 38 9	98	48 30 9	99	316
45	48 06 −7	94	48 01 −8	95	47 55 −8	96	47 49 −9	97	47 41 −9	98	315

{ For argument H.A. on the left,   True Azimuth = 360° − Tabulated Azimuth.
{ For argument H.A. on the right,   True Azimuth = Tabulated Azimuth.
No correction for date is necessary until 1944.

Sample page from "H.O. 218."

I.—CORRECTION FOR DATE TO TABULATED ALTITUDE OF STARS

t Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	t Year
1941	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1941
1942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1942
1943	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1943
1944	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1944
1945	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1945
1946	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1946
1947	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1947
1948	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	1948
1949	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	1949
1950	0	0	0	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	1950
1951	0	0	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	4	1951
1952	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	1952
1953	0	0	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	1953
1954	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	5	1954
1955	0	0	1	1	1	2	2	2	2	2	3	3	3	4	4	4	4	4	5	5	1955
1956	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	5	5	5	5	1956
1957	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4	5	5	5	5	6	1957
1958	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5	6	6	1958
1959	0	1	1	1	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	6	1959
1960	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	1960
1961	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7	7	1961
1962	0	1	1	1	2	2	3	3	3	4	4	4	5	5	6	6	6	7	7	7	1962
1963	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	7	7	7	8	1963
1964	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	1964
1965	0	1	1	2	2	2	3	3	4	4	5	5	5	6	6	7	7	8	8	8	1965
1966	0	1	1	2	2	3	3	3	4	4	5	5	6	6	6	7	7	8	8	9	1966
1967	0	1	1	2	2	3	3	4	4	4	5	5	6	6	7	7	8	8	9	9	1967
1968	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	7	8	8	9	9	1968
1969	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	1969
1970	0	1	2	2	2	3	4	4	4	5	6	6	6	7	8	8	8	9	10	10	1970
1971	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	1971
1972	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	9	10	10	11	1972
1973	1	1	2	2	3	3	4	4	5	6	6	7	7	8	8	9	9	10	10	11	1973
1974	1	1	2	2	3	3	4	5	5	6	6	7	7	8	8	9	10	10	11	11	1974
1975	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	10	11	12	1975
1976	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	10	10	11	11	12	1976
1977	1	1	2	2	3	4	4	5	6	6	7	7	8	9	9	10	10	11	12	12	1977
1978	1	1	2	3	3	4	4	5	6	6	7	8	8	9	10	10	11	11	12	13	1978
1979	1	1	2	3	3	4	5	5	6	6	7	8	8	9	10	10	11	12	12	13	1979
1980	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10	11	11	12	13	13	1980
1981	1	1	2	3	3	4	5	5	6	7	8	8	9	10	10	11	12	12	13	14	1981
1982	1	1	2	3	4	4	5	6	6	7	8	8	9	10	10	11	12	13	13	14	1982
1983	1	1	2	3	4	4	5	6	6	7	8	9	9	10	11	11	12	13	14	14	1983
1984	1	1	2	3	4	4	5	6	7	7	8	9	10	10	11	12	12	13	14	15	1984
1985	1	2	2	3	4	4	5	6	7	8	8	9	10	10	11	12	13	14	14	15	1985
1986	1	2	2	3	4	5	5	6	7	8	8	9	10	11	12	12	13	14	15	15	1986
1987	1	2	2	3	4	5	5	6	7	8	9	9	10	11	12	13	13	14	15	16	1987
1988	1	2	2	3	4	5	6	6	7	8	9	10	10	11	12	13	14	14	15	16	1988
1989	1	2	2	3	4	5	6	7	7	8	9	10	11	11	12	13	14	15	16	16	1989
1990	1	2	2	3	4	5	6	7	8	8	9	10	11	12	12	13	14	15	16	17	1990
1991	1	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16	17	1991
1992	1	2	3	3	4	5	6	7	8	9	10	10	11	12	13	14	15	16	16	17	1992
1993	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13	14	15	16	17	18	1993
1994	1	2	3	4	4	5	6	7	8	9	10	11	12	13	14	14	15	16	17	18	1994
1995	1	2	3	4	5	6	6	7	8	9	10	11	12	13	14	15	16	16	17	18	1995
1996	1	2	3	4	5	6	7	7	8	9	10	11	12	13	14	15	16	17	18	19	1996
1997	1	2	3	4	5	6	7	8	9	10	10	11	12	13	14	15	16	17	18	19	1997
1998	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14	15	16	17	18	19	1998
1999	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1999
2000	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	2000

Chapter XI.—NORTH POLAR NAVIGATION

THE APPEAL

Books, magazines, and newspapers have presented numerous maps showing that the shortest intercontinental routes in many cases pass over or near the north pole. It has even been stated that the world waits impatiently for commercial transpolar flight, and that conquest of the polar cap will be an epic adventure for navigation.

To offset this over-enthusiasm for polar routes, others have hastened to point out the difficulties of cold-weather operation, and have even tried to prove that air commerce of the future will follow the long established east-west routes and population centers of surface transportation; that air transport must go where the traffic is. The truth is probably somewhere between these two extremes.

It is certain that air traffic must continue to serve the communities established by the ancient east-west routes. It also seems certain that, with airplanes capable of such flights, in these days of shrunken global relations, there will always be a considerable amount of high priority transpolar traffic, both of men and material. The necessary bases will be established, with good accommodations for travelers who must stop over. In addition to the demands of business, many will *choose* to travel by way of the pole because of the lure of adventure, and the very novelty of the trip.

Due to these and other related considerations, the matter of polar navigation is of definite interest to all concerned with the future development of air transport whether in the government or in commercial organizations.

THE PROBLEMS

Only the problems pertaining to navigation will be considered here, omitting those incidental to climate, weather, and other engineering difficulties. The basic problems of navigation anywhere are those of distance and direction. These are especially troublesome in near-polar areas for two reasons: convergence of the meridians at the geographic pole, and the nearness of the magnetic pole.

At the equator, convergence of the meridians is zero; it increases with latitude until at the pole itself it amounts to a degree for each degree of difference in longitude. Figure 195 shows the difficulty this introduces in the matter of directions. Starting from A toward B, the true course is 000°, but upon crossing the pole it changes to 180°. In going from A to C, the initial course is 330°; at the mid-point this has

changed to 270°, and at the destination to 210°. In going from *A* to *D* the course changes from 030° to 150°—a change of 120° in approximately 240 miles.

It would be difficult, if not impossible, in any location, to make the large and continuous changes required to maintain straight-line flight under such conditions; it is made even more difficult in the polar area

AB = 278 st mi
AC = 241 st mi
AD = 241 st mi
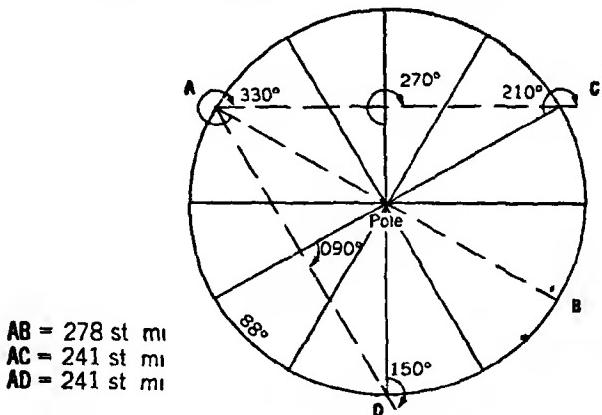
Figure 195 Excessive changes of direction near the pole.

because the magnetic compass, which normally provides the basic reference for direction in flight, is practically worthless due to the weak directive force acting on the compass near the magnetic pole.

Most charts in the polar areas contain a note such as the following:

Owing to nearness of the north magnetic pole, the force directing the compass needle is small. Under normal conditions too much reliance cannot be placed in the compass, and in times of magnetic disturbance it may become wholly useless.

Magnetic variation near the poles changes as much as 180° in a very short distance; see figure 196. In addition, our knowledge of variation in the polar areas is very limited, and considerable differences from the charted isogonic information may exist.

The foregoing and other related difficulties have led to the development of new instruments, such as the gyro-stabilized flux gate compass and the astro compass, and to the development of new techniques.

An ordinary magnetic compass is not very satisfactory within 1,000 miles of the magnetic pole; the new flux gate compass is said to furnish a satisfactory indication of magnetic directions to within about 200 miles of it. Nevertheless, it is still a magnetic compass; it is therefore limited by our incomplete knowledge of variation in the area, and is useless within about 200 miles of the magnetic pole. The astro compass provides a method of navigation independent of the earth's magnetic field; its use will be described later.

Some of these problems sound worse than they really are. The most rapid changes of direction occur close to the geographic pole, which must

always be near the mid-point of any flight through the area, and precise navigation near the mid-point of a route is less important than at the beginning and end. Also, for much of the area the changes in magnetic
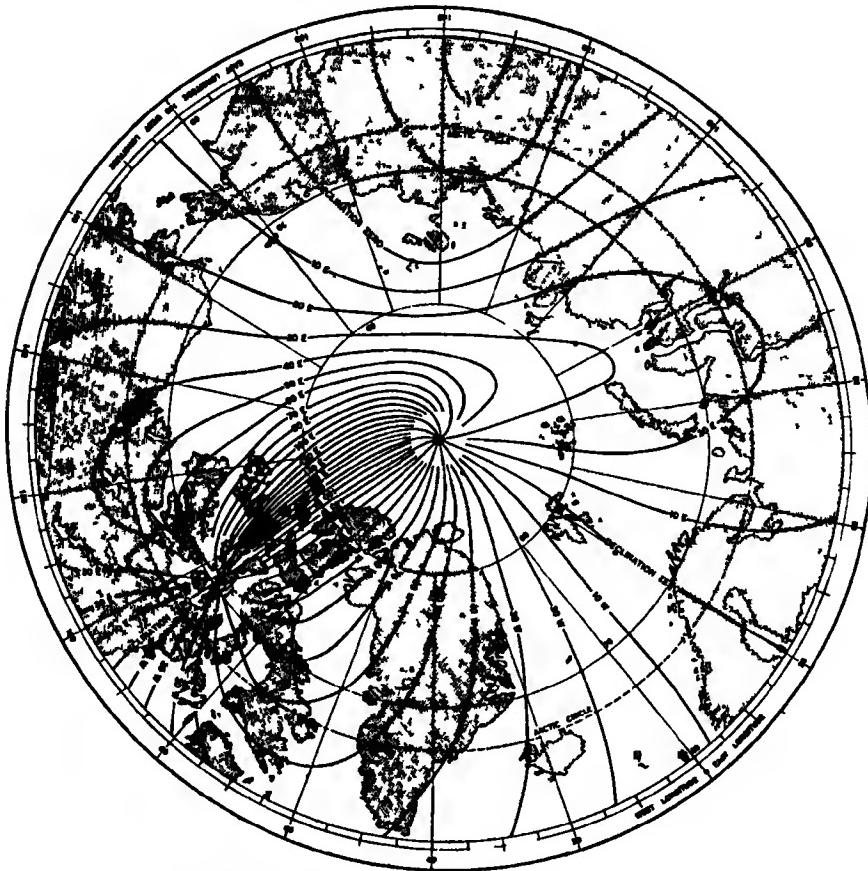
Figure 196   Magnetic variation near the north pole

variation tend to offset the changing directions due to convergence of the meridians, making the total rate of change less rapid.

CELESTIAL NAVIGATION

In polar areas, celestial navigation also has some added difficulties. During the long arctic day only the sun is visible, and a single line of position is all that is available. With the approach of winter, the sun becomes too low for satisfactory observation and finally sinks below the horizon; for some weeks, however, it is so little below the horizon that the stars are not visible against the bright sky. During this period the moon should be available part of the time, and possibly one or two of the planets.

With these exceptions, celestial navigation near the pole becomes even simpler than elsewhere. The north pole itself is always taken as the

assumed position. The meridian represented by the GHA of the observed body, taken from the Air Almanac, is always the direction of the body from the assumed position (the pole). This should be apparent from the very definition of the GHA. Finally, the computed altitude is merely the declination of the body. All that is necessary, then, is to compare the observed altitude H_o of the body with its declination as given in the almanac, and to lay off the intercept so obtained along the meridian corresponding to the body's GHA at the time of observation. The intercept is laid off from the pole (the assumed position) toward or away from the body according as the H_c is greater or less than the declination.

The substantial black dot at the lower part of figure 197 represents the earth, greatly enlarged with respect to the celestial sphere. The
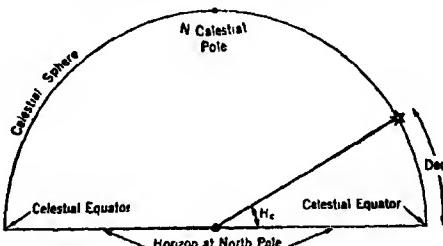
Figure 197   From the north pole, H_c is equal to the declination.

horizontal line represents the horizon of an observer at the north pole, the distance to the celestial sphere being so great that the earth's radius is as nothing, by comparison, and the observer's horizon and terrestrial equator may be considered as identical, both pointing directly to the celestial equator. From the figure it should be clear that, after all observational errors have been removed, the computed altitude H_c and the declination are both measured by the same angle.

Any transpolar flights must be for long distances, and will probably be made at high altitude for a number of reasons. They should therefore be above most storm levels, and this simple method of navigation should generally be possible. It is the writer's present belief that such flights will use this method, in combination with improved radio navigation and the best results obtainable by dead reckoning. There is also reason to believe that new instruments will make possible satisfactory dead reckoning, even under these more severe conditions. This method of celestial navigation is described in some detail, with examples, in Vol. VIII of H.O. 214.

LINE OF POSITION OR CIRCLE OF POSITION

On p. 255 it was pointed out that ordinarly a short section of a circle of position could be drawn as a straight line of position without appreciable error. When the intercept becomes long (as much as 5° or 10°) and the observed altitudes are high, this error may became important.

In figure 198 it is assumed that an LOP has been obtained from each of two bodies, resulting in the "false fix" shown. The circle of position

n each case coincides with the LOP at the meridian which represents the azimuth (GHA), but curves away from the LOP as the distance from the meridian increases. The intersection of the two circles of position, of course, represents the true fix.

Ordinarily, this method should be used only when the aircraft is within 5° or 10° of the pole. Within this limited area, unless the aircraft is several hundred miles from the meridian which represents the azimuth of the star, the difference between the false fix and the true fix just described should not exceed a few minutes of arc; the nearer the pole is
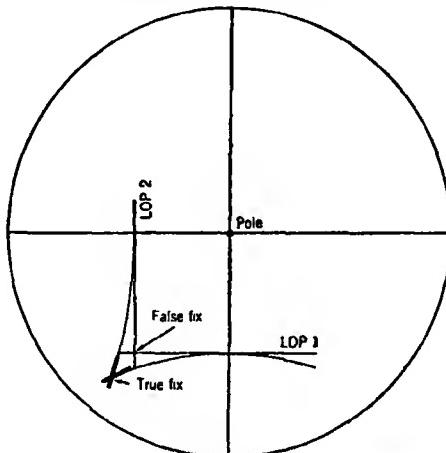
Figure 198.—Error of line of position with long intercept.

approached, the less is the error from this source. At greater distances from the pole, conventional methods of celestial navigation should be used.

If it is necessary to use a line of position from a high-altitude body, or to use this method at appreciably greater distances from the pole, an
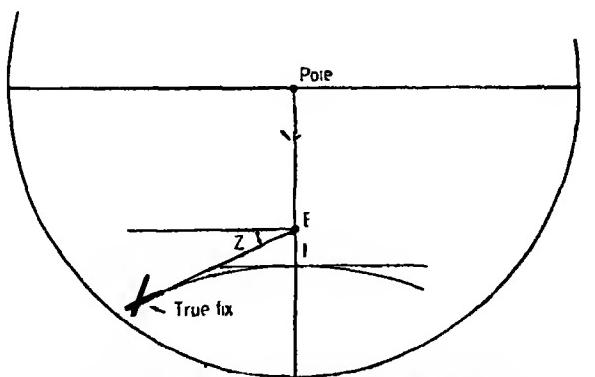
Figure 199.—The "Ellsworth method" for obtaining a true line of position.

approximate method of correction is available. In figure 199 (which is an enlargement of part of figure 198), the aircraft was actually located on the LOP tangent to the circle of position at the true fix and inter-

secting the star's meridian (GHA) at *E*. The point *E* is known as the "Ellsworth point," since it was used by the explorer on his flight over Antarctica. The Ellsworth point may be located with reference to the intercept point *I*, from table 12, which also gives the angle *Z* between the perpendicular through *E* and the desired LOP. By keeping in mind a picture of the relations shown in figure 199, the application of these two corrections should always be clear.

Note that the Ellsworth point *E* is always measured from the intercept point *I*, *away* from the star. The table is to be entered with the observed altitude and the approximate distance between the observer's position and the meridian representing the azimuth (GHA) of the body. The distance is in nautical miles, and may be obtained with sufficient accuracy by a preliminary plotting of LOPs to obtain the "false fix" illustrated in figure 198.

TABLE 12.—*Corrections for the curvature of a circle of position from a line of position*
(Ellsworth method)

Alti-tude	DISTANCE IN NAUTICAL MILES													
	100		200		300		400		500		600		700	
	E	Z	E	Z	E	Z	E	Z	E	Z	E	Z	E	Z
10° ---	0.2	0°3	1.0	0°6	2.3	0°9	4.1	1°2	6.4	1°5	9.2	1°8	12.5	2°1
15 --	0.4	0.4	1.5	0 9	3.5	1.3	6.3	1.8	9.8	2.2	14.0	2.7	19.1	3.1
20 --	0.6	0.6	2.1	1.2	4.7	1.8	8.5	2.4	13.2	3 0	19 0	3.6	25.9	4.2
25 ---	0.7	0.8	2.7	1 6	6.1	2 3	10.8	3.1	16.9	3.9	24 3	4.7	33.0	5.4
30 -	0.8	1.0	3 3	1.9	7.6	2.9	13 4	3.8	20.9	4.8	30 0	5.8	40.7	6.7
35 --	1.0	1.2	4.1	2.3	9.2	3.5	16 2	4.7	25 3	5.8	36 2	7 0	49.2	8.1
40 --	1.2	1.4	4.9	2.8	10.9	4.2	19 1	5.6	30 2	7 0	43 3	8.3	56 6	9.7
45 - -	1.4	1.7	5.8	3.3	13.0	5 0	23.0	6 6	35 7	8 3	51.2	9.9	69.2	11.5
50 --	1 7	2.0	6.9	4.0	15.5	5 9	27.4	7 9	42 4	9 8	60.4	11.7	81.3	13.6

THE "G SYSTEM" OF DIRECTIONS

In order to avoid the nuisance, which amounts to almost an impossibility, of rapid changes of direction for even a short flight near the pole, the G system of directions has been proposed. Under this system a series of grid lines is drawn or printed on the navigator's chart, at any desired spacing, but all parallel to the meridian of Greenwich. These are in addition to the conventional meridians and parallels, and might well be in some different color, to avoid any confusion. All directions are measured with reference to these grid lines, the direction from Greenwich toward the pole (and beyond it) being considered as 0°, the direction from the pole toward Greenwich being 180°. The customary 360° system is used, but in order to distinguish "G directions" from those referred to conventional north, they are written with a small capital "G" instead of the usual degree mark. Thus a direction of 105° with respect to this new and arbitrary grid is written: 105ᴳ. Figure 200 shows an ordinary polar stereographic projection with the G system of grids shown by broken lines. A line representing a true course of 250ᴳ is also shown; note that

the direction is 250^G across the whole projection. (Point A and angle X will be referred to in a later portion of the text.)

An additional feature of this proposed system of directions is the use of "isogonic lines" which will combine the correction for magnetic variation and a correction for convergence of the meridians. These "synthetic" isogonic lines would be much more widely spaced than the real isogonic lines, making changes in magnetic direction much less fre-
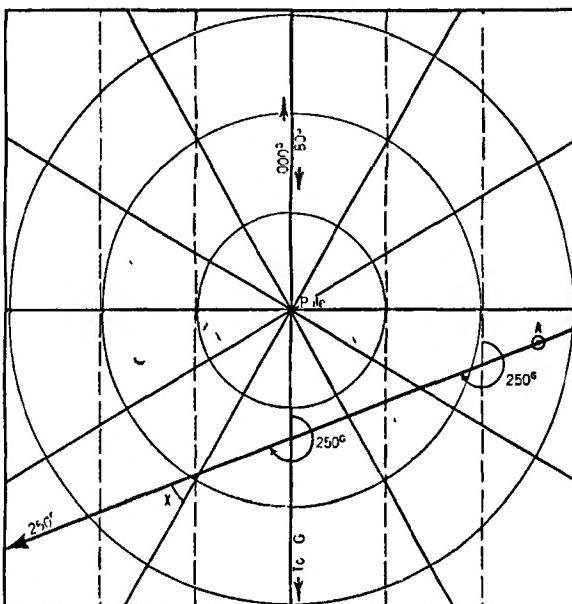
Figure 200 —Directions referred to the G (Greenwich) grid.

quent. The net result of the method, in areas where some form of the magnetic compass is usable, would be comparable to the use of the Mercator projection in equatorial latitudes, where a straight line approximates a great circle; courses may be measured at any convenient meridian; and the application of magnetic variation provides a magnetic heading that can be flown for a reasonable period of time. One writer on polar navigation has referred to the correction afforded by these synthetic isogonic lines as "G-viation."

It has been pointed out that for an observer at the pole the GHA of the body indicates its direction, or the meridian along which it will be found. From figure 200 it may be seen that the azimuth of a star in terms of the new system will differ from the GHA by 180°. Thus, if the GHA is 30° (meridians are at 30° intervals in the figure), the azimuth in terms of G is 30° + 180° = 210^G; if the GHA is 330° the azimuth in terms of G is 330° — 180° = 150^G.

Again, to an observer at the pole all celestial bodies appear to rotate parallel to the horizon, 360° in 24 hours, 15° every hour, or 1° every 4 minutes. That is, the direction of the star with reference to the meridian of Greenwich, changes 1° every 4 minutes.

FLYING "G" COURSES

Having established a new set of "meridians," there still remains the problem of maintaining a G-direction of flight, since we have no "G-seeking compass" to furnish the desired reference. The answer is found in the combined use of the directional gyro and the astro compass. As mentioned in Chapter IV, the aircraft gyro has no directional properties of its own, but must be set at frequent intervals because of precession. The magnetic compass is useless for this purpose near the pole, and is therefore replaced by the astro compass; see p. 72.

Referring again to figure 200, suppose that a flight is starting from A, on true course 250^G. The GHA of the sun at that moment is 30°; this means that the sun lies along the first meridian to the west of Greenwich in the figure, which makes an angle of 30° with the meridian of Greenwich. Knowing also the direction of the true course with reference to the meridian of Greenwich, it is easy to determine that the angle X is equal to 40°; that is, for an airplane at that point, headed along the true course, the relative bearing of the sun is 40° left. Since the sun is so far from the earth that all its rays are parallel, the relative bearing of the sun for an aircraft at any other point along the same plotted route, at the same moment, is also 40°.

Using the astro compass as a pelorus, the relative bearing of 40° is set off on the azimuth circle of the instrument, and the airplane is turned until the sun's shadow line appears on the shadow screen. At that instant the airplane is headed along the desired track; the directional gyro is set at 0°, and the heading maintained for the next 10 or 15 minutes by gyro.

In the above procedure the curvature of the earth is ignored and the polar area is considered as a plane. Within 5° of the pole the maximum error in direction from this assumption is about 2°, which is scarcely of practical importance in that area. At latitude 75°, the error may reach 5° or 6°, and precise conventional methods should be used when possible.

Continuing the assumption of the polar area as a plane surface, we know that the sun's azimuth changes 1° in every 4 minutes (see p. 313) with respect to the meridian of Greenwich. In 12 minutes, then, the initial relative bearing of 40° will have changed to 37°. This bearing is set off on the azimuth circle and the sun's shadow is again brought to the shadow screen (by turning the aircraft as necessary); the directional gyro is reset to 0°, and that heading maintained by gyro, as before. In this way the gyro is reset as often as necessary to correct for precession. The procedure is the same for a star, except that the star is brought into line with the sights (since it casts no shadow).

If the wind direction is changed to the G system also, all wind triangles may be solved with computers, or graphically, in the usual way.

RADIO NAVIGATION

When polar routes are established commercially, the usual radio aids will undoubtedly be constructed as well. In the meantime, it is

known that the present working radio frequencies are not suitable in polar areas due to reflected sky waves and related difficulties common in high latitudes. For this reason, even in Alaska, it is often possible for a pilot to hear the signals of a radio range station (of moderately low frequency) when the communicator at the station is unable to receive his call (at higher calling frequency).

With the adoption of suitable frequencies, the use of the radio range in the arctic should normally differ in no way from its use elsewhere.

Radio bearings might be plotted at the geographic meridian nearest the assumed position, but this would be rather a weak method, in view of the difficulty of determining a true north reference point. A better procedure would be to observe all bearings as *relative* bearings with reference to the true heading of the airplane in degrees of the G system. These are readily converted to G bearings, which may be plotted from any convenient G "meridian" without correction. If preferred, the reciprocal of the G bearing can be plotted directly from the station, using a G grid meridian as reference, without correction of any sort.

Another possibility in polar regions would be to establish ground direction finding stations, the positions of which would be definitely known and charted, with a true compass rose around each station. A bearing reported by radio to the pilot from such a station could be plotted on the chart at the geographic meridian through the station, without correction of any kind, and would furnish a positive line of position.

SUMMARY

The G grid system provides a relatively simple method of straight line flying in polar areas. Although no aeronautical charts containing this grid have yet been issued for general use, it is possible that it, or some simpler system, may yet be adopted as standard.

The whole question of polar navigation is under intensive investigation at the present time, and this brief treatment is included to provide the student with a general picture of some of the problems peculiar to the region, and of the solutions favored at the present time (1944). Even in the near future, new instruments and methods may permit simpler procedure and more accurate results.

EXAMPLES

Example 1.—In the vicinity of the north pole, on January 10, 1944, at 1847 GCT, the observed altitude of Arcturus was 17°06′ and of Pollux 27°35′. Find the latitude and longitude of the observer.

From the Air Almanac the GHA is found in the usual way, and the following data are tabulated:

Arcturus
$$GHA = 177° \ 38'$$
$$dec. \ (H_c) = 19 \quad 28$$
$$H_o = 17 \quad 06$$
$$a = 2 \quad 22 \ \text{(away)}$$

Pollux
$$GHA = 275° \ 27'$$
$$dec. \ (H_c) = 28 \quad 10$$
$$H_o = 30 \quad 25$$
$$a = 2 \quad 15 \ \text{(toward)}$$

Arcturus lies along the meridian of 177°38′ west longitude; the intercept of 2°22′ is plotted AWAY from the star, 2°22′ on the opposite side of the pole, and the line of position is drawn.

Pollux lies along the meridian of 275°27′ west longitude, or 84°33′ east longitude. The intercept in this case is laid off from the pole TOWARD the star, since the observed altitude is greater than the declination (H_c).

The intersection of the two lines of position determines the latitude of the observer as 87°10′ N., the longitude as 45°50′ E.

Example 2.—January 20, 1944, at GCT 0615, in dead reckoning latitude 79° N., longitude 60° W., the following altitudes were observed: Arcturus 24°50′, Pollux 36°53′. Find the geographic position of the observer.

From the above and the Air Almanac the following data were available:

Arcturus			Pollux		
GHA =	358°	59′	GHA =	96°	48′
dec. =	19	28	dec. =	28	10
H$_o$ =	24	50	H$_o$ =	36	53
a =	5	22 (toward)	a =	8	43 (toward)

Lines of position from these data were plotted as in example 1, resulting in a "false fix" at latitude 79°02′, longitude 59°45′. This fix was about 600′ (nautical miles) from the meridian of Arcturus, and 400′ from the meridian of Pollux. With this information, table 12 was entered, and the following data for plotting the Ellsworth corrections were obtained:

Arcturus: E   24.2,   Z   4°6
Pollux: E   16.1,   Z   4°7

After these corrections were applied the true position of the observer was determined as latitude 78°34′ N., longitude 59°00′ W.

Example 3.—A flight is to be made from a fictitious base on Ellesmere Island to Murmansk, and the true course is determined as 130^G. At Ellesmere Island (lat. 83° N., long. 70° W.), the wind is 000° and 32 mph; at a base in Peary Land (lat. 83°30′ N., long. 30° W.), wind is reported as 040° and 35 mph; and from Spitsbergen (lat. 78° N., long. 17° E.), it is reported as 090° and 33 mph. Navigation will be a combination of dead reckoning and celestial navigation, with radio bearings from stations at the points of origin and destination and from Reykjavik.

For dead reckoning, the first step is to convert the wind from true directions to G directions. The wind at the Ellesmere Island base, 000°, is found as 070^G: 000° + 70° west longitude. (Note: In this case, 180° need not be added as described on p. 312, since it is the direction *from* which the wind is blowing that is required.) At Peary Land the wind of 040° is found as 070^G: 040° + 30° west longitude; and the wind of 090° at Spitsbergen is found as 073^G: 090° —17° east longitude. From this it is seen that throughout the whole area the wind is of approximately uniform velocity, and of uniform direction with reference to the meridian of Greenwich.

A wind triangle is now set up on the computer, setting the course of 130^G at the true index, and the wind at 070^G. With the wind velocity of 35 mph and the true air speed of 210 mph, the true heading is determined as 122^G, and the ground speed as 191 mph.

The flight is to be made on June 10, 1944, starting at 1130 GCT. From the Air Almanac the GHA of the sun for that instant was determined as 352°41′—that is, its bearing with reference to the meridian of Greenwich is 172°41′ (remember that the direction from the pole toward Greenwich is considered as 180^G). The relative bearing of the sun, then, is 42°41′ to the right of the true course of 130^G, or 50°41′ right from the true heading of 122^G. The take-off is made in advance of the scheduled departure, and the airport is circled for altitude. Using the astro compass as a pelorus, the relative bearing of the sun from the desired true heading is set on the azimuth circle, the airport is crossed at 1130 and the aircraft turned until the sun's shadow falls on the shadow screen. The directional gyro is set to 0°, and the flight proceeds as described earlier.

During the early part of the flight the track is checked by radio bearings to the station at the Ellesmere Island base. These are observed as relative bearings from which they are most readily converted to G directions, after which they may be plotted at any convenient "meridian" of the G grid, without correction.

At 1330 the relative bearing of Reykjavik was determined as 79°, which is equivalent to 201^G: the true heading of 122^G plus the relative bearing of 79°. This bearing may be plotted from any convenient G "meridian," to pass through the station, or its reciprocal may be plotted from a G meridian through the Reykjavik station without correction of any kind. When this was done the 1330 position of the airplane was determined as latitude 83°35′ N., longitude 22° W.

The flight proceeds, with all the above operations frequently repeated, resetting the gyro from time to time by relative bearings of the sun. Lines of position are also obtained from sextant altitudes of the sun, checking the track and progress along the route at different times of the day, as the azimuth of the sun changes. Finally, the radio station at Murmansk is used for homing during the last hour or so of the flight.

QUESTIONS

1. What are some of the advantages and disadvantages of polar flight?

2. State some of its peculiar difficulties.

3. Is any method of navigation less difficult in polar areas than elsewhere?

4. Why is even the flux gate compass of limited usefulness near the poles?

5. What is the preferred method of computing the altitude of a celestial body when the pole is used as the assumed position?

6. For an observer at the pole, what is the relation between the GHA of a body and its azimuth?

7. What is meant by an "Ellsworth point," and how is it used?

8. What is meant by the "G system"?

9. On a course of 270ᴳ, what will be the relative bearing of a body with GHA 40°? Of one with GHA 320°?

10. What instrument is used in polar navigation for setting the directional gyro?

PROBLEMS

In the absence of a suitable chart for plotting the following problems, a pad of 50 "Maneuvering Board" diagrams, known as H.O. 2665a, may be obtained from the Hydrographic Office, U. S. Navy Department, Washington 25, D. C., for 60 cents. These are very convenient bases for plotting problems in polar navigation, and may easily be ruled with the G system of grid lines. In the absence of a plotting board of the Mark 3A type, these diagrams may also be used for such problems as radius of action, interception, and other similar work.

1. At 1700 GCT, December 3, 1944, from a position near the north pole, after all corrections are applied the following sextant observations are obtained: Regulus 15°09'; Aldebaran 18°09'. Find the geographic position of the observer as lat. 87°02' N., long. 175°20' E.

2. At 2323 GCT, December 22, 1944, on a transpolar flight, the following corrected sextant observations are obtained: Arcturus 23°11'; Capella 40°49'; Vega 43°44'. Find the geographic position of the observer, at the center of a small triangle of error, as lat. 84°47' N., long. 177°25' E. Disregard the Ellsworth correction in this problem.

3. At 0747 GCT, June 26, 1944, when near the pole, the following corrected sextant observations are obtained: sun 29°47'; moon 9°22'. Find the position of the observer as lat. 81°37' N., long. 24°35' E. (Note: Although they are not large, Ellsworth corrections are used in this problem.)

4. An airman is at latitude 85° north, on the meridian of Greenwich. In terms of the G system, in what direction will he fly if he travels—

   (a) toward the pole;
   (b) toward Greenwich;
   (c) at right angles to the meridian of Greenwich, in an easterly direction;
   (d) At right angles to that meridian in a westerly direction?

5. Assume that a flight is started from an air base at lat. 82°30' N., long. 70°00' W., on a true heading of 070ᴳ. After an extended period of flying, a relative bearing of 120° left was obtained, toward a station located at lat. 85° N., long. 130° W.; within a minute or two later, a relative bearing of 130° right was obtained toward a station at lat. 85° N., long. 20° W. Find the position of the aircraft (at the north pole).

6. A flight is to be made from the fictitious base on Ellesmere Island (lat. 83° N., long. 70° W.) to another island base at lat. 80° N., long. 95° E.

From a weather station at the pole itself, wind is reported as "from the south," at 31 knots. From a station at lat. 87° N., long. 80° W., wind is reported as 220° true, 30 kt.; from a third station at lat. 85° N., long. 80° E., wind is reported as 020° and 32 kt. True air speed is 185 kt. The take-off is to be made on July 3, 1944, at 1652 GCT.

Find the data for the flight as follows:

$$TC = 78^G\ 30'$$
$$Wind = 300^G,\ at\ 31\ kt.\ (average)$$
$$TH = 72^G$$
$$GS = 217\ kt.$$
$$R/B\ sun = 180°\ (\text{"R/B"} = relative\ bearing).$$

Chapter XII.—THE PRACTICE OF NAVIGATION

DETAILS OF NAVIGATION

The art of navigation is made up of many details, each varying somewhat with the changing conditions of flight. In order to present the procedures under these different situations, considerable explanation seems necessary, and there is some danger of becoming lost in the details.

The basic principles are comparatively simple. If they are kept in mind, they should point the way to the solution in each case, regardless of the varying conditions. This chapter has been prepared in an effort to correlate the individual steps, and to emphasize the simple procedures in the practice of air navigation.

PREPARATION OF CHARTS FOR USE IN FLIGHT

The route to be flown, if at all long, is plotted on a planning chart, then transferred to the chart to be used in flight. The plotted route on the flight chart is next marked in 10- or 20-mile intervals, with the mileage indicated at 50- or 100-mile intervals. The spacing dividers shown in figure 201 are very convenient for this purpose. The scale of miles along the route makes it easy to estimate distance made good and ground speed.

Major landmarks and check points along the route are boldly circled in pencil, and radio bearings at about 10° intervals are plotted from each radio station likely to be used for radio bearings. In flight, with the ground speed known, the time for reaching each landmark may be obtained (by computer or spacing dividers), and noted beside it on the chart, making it easier to identify the feature and to check progress along the route.

A flat chart is desirable for study and lay-out of routes; in flight, except in large aircraft, it is inconvenient, if not impossible to handle. In order to avoid the handling of numerous charts even for short trips, and the resulting annoyance in all navigational problems, both sectional and regional

Figure 201.—Spacing dividers.

charts have been designed to cover fairly large areas; nevertheless, charts of both series will be found very convenient for use in the air when properly folded. It is recommended that the charts be folded once, back to back, along the line AB (fig. 202), then in 4 or 6 "accordion folds" in the other direction, along the vertical broken lines indicated in the figure. In this way the entire chart may be consulted merely by turning over the accordion folds.

Strip charts are very convenient for those flying frequently over the same route, but they cannot fully satisfy the need, even for this type of

flying. A pilot may be compelled to leave the charted airway, because of adverse weather conditions or other reasons, and find himself over unfamiliar territory with no chart of the ground below. If a strip chart is prepared showing only the region immediately adjacent to the route, complete charts showing a wider area, folded for most convenient reference in case of need, should also be carried.

If a strip chart is desired and an additional chart is not available for reference in an emergency, the chart can be folded as a strip without destroying or cutting away any part of it. For example, if it is desired to make a strip chart covering the route *CD* (fig. 203), fold the chart so as to leave the route in the center of a strip 10 or 12 inches wide; then fold the strip in the accordion fold illustrated in figure 202. By this method the
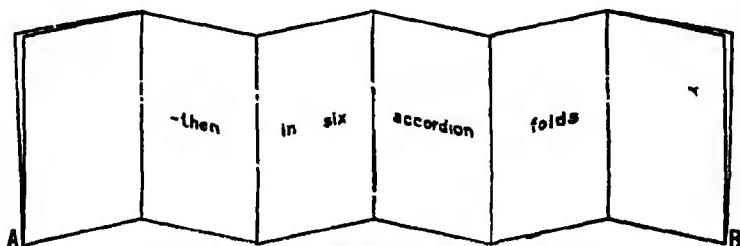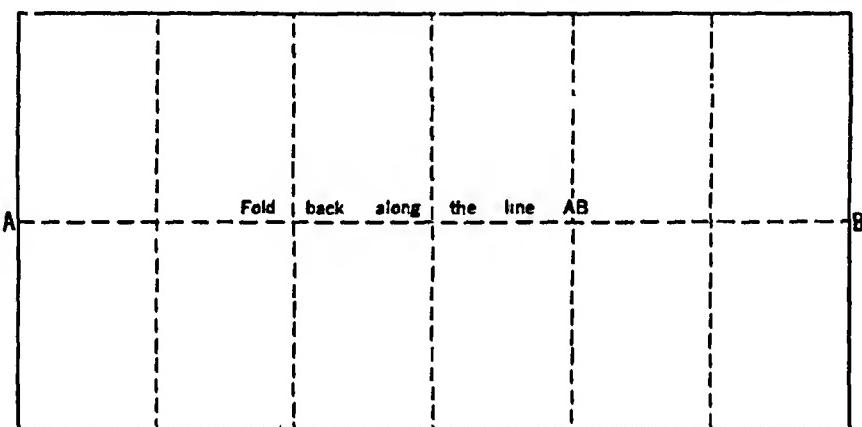
Figure 202.—Folding the chart for use in flight.

folded-back portions of the chart are still available if they should be needed.

In describing the folding of charts, all the illustrations have shown the route as complete on a single chart. Unfortunately, it seems seldom to work out that way in practice. If it is desired to fly from *A* to *B* (fig. 204), even though the distance is not great, the route sometimes requires parts of four charts. For this situation, a strip chart made by pasting together parts of the four charts will be found very convenient. If it is desired not to cut away or destroy the areas not wanted for this particular route, each of the charts may be folded in one of the ways already illus-

trated. For example (fig. 204), chart 1 should be folded as shown in figure 203; charts 2, 3, and 4 as shown in figure 202, with the corner nearest the junction exposed in each case. A little thought given to the most suitable manner of folding the charts for each new combination that may arise will be found well worth while in flight.
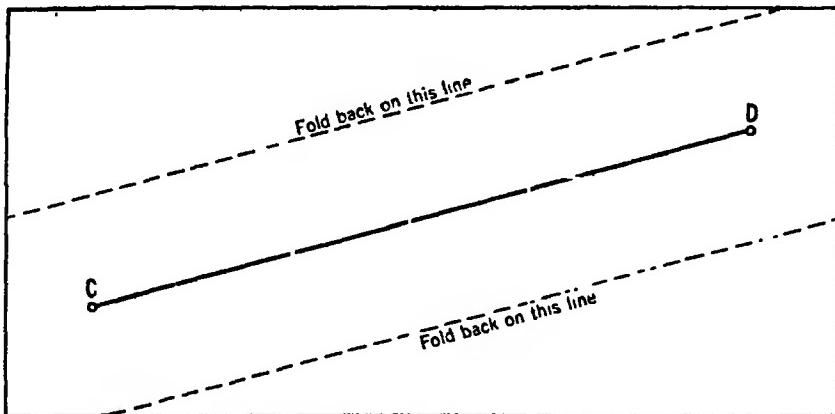
Figure 203.—Folding the chart as a strip.

Whenever charts or portions of charts are to be joined together, as is often the case when making up strip charts, rubber cement should be used, since it does not cause the wrinkles and distortions so common when using
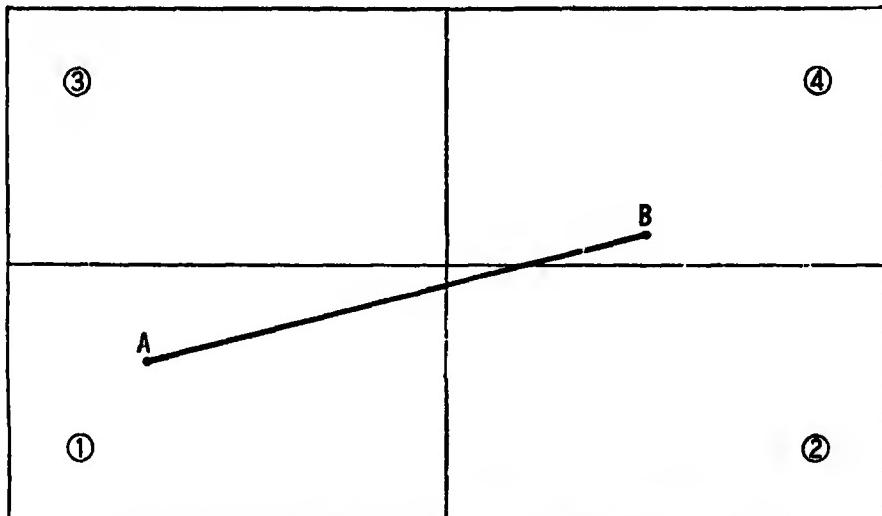
Figure 204.—Folding four charts for a route near their common corner.

other adhesives. If a thin coat of rubber cement is applied to both the surfaces to be joined, and allowed to dry before pressing the surfaces together, a fairly permanent junction can be made.

PILOTAGE

With the charts all prepared, an example of pilotage, or landmark flying, will be considered first. This type of flying is so generally under-

stood and practiced that it is scarcely necessary to give an example; however, suppose that it is desired to fly from Yakima Airport to Fancher Airport, at Wenatchee (pl. IV). After taking off from Yakima, the desired altitude is gained while skirting either edge of the city; the Yakima River and the main highway and railroad track along it are then picked up and followed through the rough gorge toward Ellensburg. The beacon on the ridge to the left is a check on position near Wymer. The same general heading is maintained until the irrigation canals of the Ellensburg Valley are crossed, with the city of Ellensburg 3 or 4 miles to the left. Even from this distance the "vista," or cut-over path where the power line goes over the ridge to the north is clearly seen, and the heading is changed to pass between the power line and beacon 10, roughly along the secondary road leading to the Columbia River. With this heading, the approaching mountain ridge can be crossed without climbing to a high altitude. The Columbia River comes into view as soon as the top of the ridge is passed, and the city of Wenatchee can be seen up the river, a little to the left. The airplane is then headed for Fancher Field, which may be seen on top of the first shelf northeast of the city, between the main road and the secondary road.

In order to keep on the desired route, it is a good practice whenever possible to select two landmarks ahead, which are known to be on the course, and fly the airplane so as to keep the two objects in line. This is known as flying a range. Before the first of the two landmarks is reached, another more distant object in line with them should be selected and a second range flown. In addition to other advantages, this type of flying automatically takes care of the correction for wind.

To illustrate the use of ranges under conditions of good visibility and ceiling, suppose that a flight is planned from Yakima Airport to Boeing Field, at Seattle (pl. IV). A straight line drawn between these two points on the chart at first appears to be a desirable route, with the Naches River valley and highway furnishing an excellent series of ranges for the first portion of the flight. From a further study of the chart, however, and from local information, this route is decided against as being in large measure over high, wooded terrain with few spots level or clear enough for emergency landings. Consequently, the Yakima River and railroad are followed, as in the previous example, to Ellensburg, Cle Elum, and Easton, by ordinary pilotage.

A few miles west of Easton, the Northern Pacific Railroad turns left, through a tunnel, to Stampede. The transmission line, with its wide vista through the timber, is followed over Stampede Pass, and along the railroad to Lester.

From Lester to Palmer, the railroad itself furnishes an excellent series of ranges. From Palmer the following points are lined up in turn to furnish a series of ranges: Palmer and Ravensdale; Ravensdale and Maple Valley; Maple Valley and the ponds northeast of Lake Youngs; the ponds and the water tower; the water tower and Renton; and Renton and Boeing Field.

CONTACT FLYING

Contact flying may be considered generally as a combination of land-mark flying and dead reckoning. To illustrate it, suppose that a flight was planned from the Omaha municipal airport to the municipal airport at Joliet (28 miles south of Chicago) with one stop at Moline Airport (Illinois) for refueling. The Des Moines and Chicago sectional charts were to be used.

The straight-line route from Omaha to Moline lies well to the right of the civil airway, and therefore satisfies the requirement of keeping to the right. Since this portion of the route covers about 5½ degrees of longitude, the straight line was broken into two sections, at Indianola (south of Des Moines). The portion of the route between Moline and Joliet was also broken into two sections, the change of course in this case being made near the town of Sheridan, for reasons to be explained later. The data for the four sections of the route were as follows:

Section of route	True course	Magnetic variation	Miles	Total
Omaha–Indianola	087°	8° E	122	
Indianola–Moline	088°	6° E	158	280
Moline–Sheridan	087°	4° E	96	
Sheridan–Joliet	090°	3° E	28	124

The trip was to be made in accordance with contact flight rules, and the airplane was not equipped with radio. It was planned to leave Omaha early on April 18, 1940, but at the airport weather bureau office it was learned from the 7:30 a. m. map [11] that a low-pressure area was centered to the north of Lake Erie, and that precipitation and low ceilings and visibility existed west of Chicago. At Omaha, visibility was only three-fourths mile, and contact flying was not permitted.

When the 1330 weather map was posted in the afternoon it was seen that ceilings had lifted, and there was no precipitation west of Pennsylvania. It was planned to fly at altitudes not more than 1,000 feet above the ground, and therefore only the surface winds were of interest.

At Omaha, the surface wind was northwest, about 7 mph.

At Des Moines, surface wind was not shown, but a layer of stratus clouds was shown, moving southward at 2,000 feet.

At Moline, surface wind was ENE, 7 mph; cumulus clouds moving southward at 3,000 feet.

At Chicago, surface wind was NNW, about 18 mph.

The cruising speed of the airplane was 120 mph, and the correction for wind was found as 3° for the first section; ground speed 124 mph. In addition to the pilot's wrist watch, the only chronometer carried was a dollar watch. With the watch set to 12 o'clock at the time of taking off,

[11] Weather information for this example has been taken from Weather Map D-1, of Civil Aeronautics Bulletin No. 25, Meteorology for Pilots, which may be consulted, if desired, to verify the data and values used.

the time registered by it thereafter is the elapsed time of flight. With his computer set for the ground speed, and a knowledge of the elapsed time, the pilot may estimate his position along the route at any time, with considerable accuracy. Later, as positions are identified from time to time in flight, the elapsed time is written on the chart adjacent to the feature. This provides the means for rechecking ground speed.

No flight plan was filed, and the flight was cleared by the Omaha control tower at 1530. After circling for altitude, the airplane was turned to the compass heading for the first section, which was 076° (087° —3° WC —8° var. + 0° dev. = 076°).

The pilot now began to check the accuracy of his compass heading by landmarks. An excellent check was obtained just 4 minutes from Omaha, in crossing the CGW railroad, about 8 miles distant. The true course plotted on the chart passed just to the north of the short east-west section of the railroad, as shown in figure 205; the pilot found that he crossed the
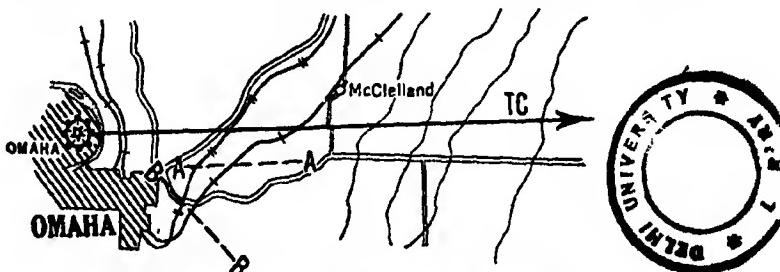
Figure 205.—Checking the track by the angle and position of crossing railroads.

railroad in just about this position, confirming the accuracy of his compass heading.

If the wind had been stronger, or more northerly, and the same heading were flown, the crossing would have been as indicated at *AA* in the figure, and additional correction should have been made for wind.
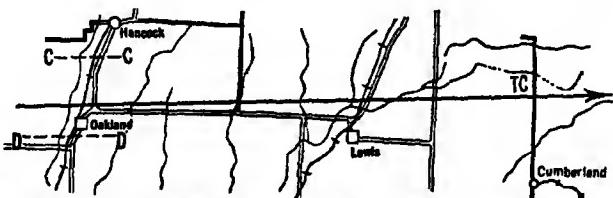
Figure 206.—Checking the track by cultural and topographic landmarks.

If the compass heading were considerably in error for any reason, the crossing might have been as at *BB*. The angle and the position of crossing not only check position, but indicate the nature and even the amount of any additional corrections that may be required.

Similar checks were obtained at Oakland (13 minutes from Omaha) and Lewis (about 21 minutes from Omaha), as shown in figure 206. At Oakland, a crossing of the stream, railroad, and highway pattern at any

other point (as *CC*, or *DD*) could easily have been detected. At Lewis the same is true; in addition, the east-west section of the stream provides a further definite check. A crossing at any other point would have been readily apparent. The straight section of highway between Oakland and Lewis, so nearly parallel to the route, also furnishes an excellent check on the compass heading.

Shortly after passing Lewis it became apparent that the airplane was being drifted somewhat south of the intended track. This was in keeping with the southward moving clouds noted at Des Moines on the weather map. No change was made in the heading, however, until Martensdale was identified, about 15 miles southwest of Des Moines. The unusual railroad pattern here could not be mistaken; see figure 207. The railroads

Figure 207.—Railroad pattern at Martensdale, Iowa.

were picked up to the south of Martensdale, and were followed back to the position of the plotted route.

It was seen from the mileage ticks along the route on the chart that Martensdale was about 60 miles from Lewis. The airplane had been about 3 miles south of the intended track at Martensdale, and an error of 3 miles in 60 meant an error of 3° in the compass heading.

The compass heading was to have been changed at about this point from 076° (the heading for the first section) to 079° (088° — 3° WC — 6° var. + 0° dev. = 079°), for the second section. An additional 3° correction for wind was applied, which made the compass heading 076°.

With only minor variations, the same procedure was followed until the Mississippi River was sighted near Muscatine, and followed in to Rock Island and the Moline Airport.

Landing was made at Moline at 2:20 by the dollar watch, 5:50 by the pilot's wrist watch, indicating an average ground speed of exactly 120 mph for the 280 miles. The first section had been at about 124 mph, the second at about 118 mph.

At 6:15, the take-off was made for Joliet, with the dollar watch again set to 12 o'clock. The course had been plotted from Moline to the railroad junction just west of Sheridan. This junction was selected as the turning point for two good reasons. First, it is well to the right of the airway, and thus meets the requirements of right side traffic. Second, the railroad pattern provides an ideal check point; see figure 208. If the airplane is directly on course with this pattern, the converging railroads

can scarcely be mistaken, the point of intersection is definitely fixed, and the new heading can be assumed with certainty.

If the airplane is too far to either side, as at *E* or *F*, the angle at which the railroad is met is positive notice of the direction off course, the railroad is followed to the point of intersection, and the new heading
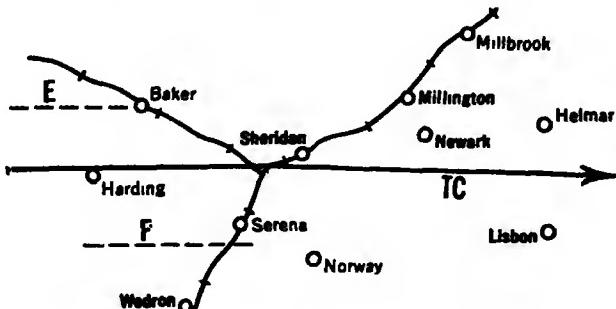
Figure 208.—Railroad pattern near Sheridan, Illinois.

assumed with an added correction based on the estimated distance the airplane was off course.

The junction was reached at 12:48 by the dollar watch, 7:03 by wrist watch, with just sufficient daylight to identify it. The airplane was turned to the final heading for the Joliet Airport, and landing was made at 7:18 p. m., 1 hour and 3 minutes from Moline.

INSTRUMENT FLYING

The details of instrument flying having been given elsewhere, at this point there will be given only the procedure of a hypothetical instrument flight. The following example is adapted from an instruction manual of the Air Traffic Control Division, prepared for its own use. It is included here primarily to acquaint pilots with the facilities and services available to them in instrument flight, which are illustrated in the fictitious chart of figure 209.

One day, John Doe decided to make a flight from Summit Airport to Valley Airport. His aircraft was a Stinson with identification number NC 1234, equipped with two-way radio plus all instruments required for flight without visual reference to the ground.

Before going to the hangar he consulted the meteorologist, who informed him of the weather, and of the wind directions and velocities at various altitudes along his route. With these data he was able to choose the altitude offering the most favorable winds.

Having prepared his instrument flight plan, he picked up his microphone and called the airport control tower, as follows:

"SUMMIT TOWER THIS IS STINSON ONE TWO THREE FOUR IN FRONT OF THE ADMINISTRATION BUILDING WOULD LIKE TO SUBMIT A FLIGHT PLAN."

The control tower operator replied:

"STINSON ONE TWO THREE FOUR THIS IS SUMMIT TOWER, OVER."

The following information was then submitted, as required by the Civil Air Regulations:

Aircraft identification mark	NC 1234.
Type of aircraft	Stinson.
Pilot's last name	Doe.
Point of departure	Summit.
Proposed altitude and route	11,000 direct.
Point of first intended landing	Valley.
Cruising air speed	130 mph.
Radio transmitting frequency	3105 kcs.
Proposed time of departure	1400E.
Estimated elapsed time for flight	1 hr. 50 min.
Alternate airport	Athens.
Hours of fuel supply on board	4 hrs. 25 min.

The tower relayed this flight plan to the Airway Traffic Control Center and a controller checked the flight progress board (a graphic record of all flights) to see if this flight would conflict with other aircraft flying at the same altitude and in the same direction. While this was being done, the control tower operator issued taxi instructions to Doe as follows:

"STINSON ONE TWO THREE FOUR CLEARED TO RUNWAY THREE SIX, WIND NORTH ONE ZERO, ALTIMETER THREE ZERO FOUR, TIME, ONE THREE FIVE SEVEN HOLD WEST OF THE RUNWAY."

(In radio communications numbers are spoken as digits, for purposes of clearness. The 24-hour clock is used and, when no misunderstanding can result, time is given in minutes only.)

The above clearance requested Doe to use runway 36 (= direction of 360°), since a take-off is made into the wind. By the time Doe had reached the south end of the runway, Airway Traffic Control had completed its check, and the control tower operator forwarded the ATC clearance, as follows:

"STINSON ONE TWO THREE FOUR ATC CLEARS YOU FROM SUMMIT TO BEAR LAKE, CRUISE AT ELEVEN THOUSAND, CONTACT BEAR LAKE RADIO AS SOON AS POSSIBLE, OVER."

After Doe had repeated the clearance back to the tower to avoid any possibility of error, the tower then advised him of the local traffic:

"STINSON ONE TWO THREE FOUR AN AMERICAN DOUGLAS REPORTED EIGHT MILES NORTH, FIVE SEVEN AT ONE THOUSAND EIGHT HUNDRED DESCENDING, LANDING SUMMIT, CLEARED FOR TAKE-OFF."
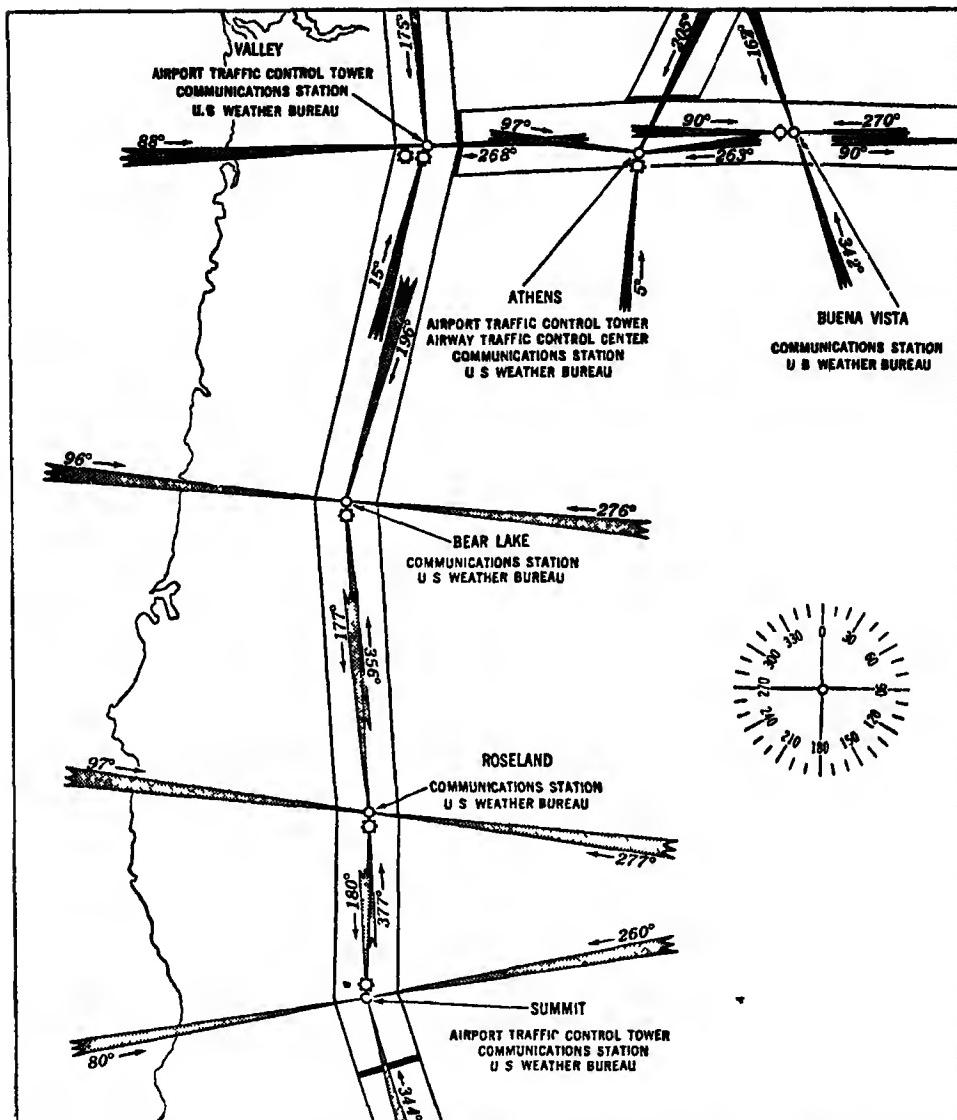
Figure 209.—Portion of hypothetical airway traffic control area on which typical instrument flight is based.

Setting his brakes and testing the engine for a final check-up, Doe then released the brakes and was on his way. This entire procedure from the time Doe called the tower to the time he took off amounted to only 4 minutes.

The actual departure time was forwarded by the airport tower to ATC, and the controller receiving the information recorded on the flight progress board Doe's expected arrival times over the points where he would report his actual progress: the times of passing over the Roseland and Bear Lake range stations, and arrival at Valley Airport. By posting these data, the center would have the information necessary to protect

Doe from collision with other aircraft, by issuing further instructions. if necessary.

Doe climbed immediately to 11,000 feet, his prescribed cruising altitude, and kept to the right side of the beam. After 10 minutes' flying time he tuned his radio to the Roseland radio frequency. When passing over the Roseland station, he contacted the communicator and advised him as follows:

"ROSELAND RADIO THIS IS STINSON ONE TWO THREE FOUR, OVER ROSELAND RANGE STATION TWO ZERO AT ELEVEN THOUSAND, ONE ONE THOUSAND, OVER."

The aircraft communicator repeated his position report and forwarded it to the Airway Traffic Control Center where the record of Doe's progress was being kept.

Twenty-five minutes after passing Roseland, Doe tuned his receiver to the Bear Lake radio frequency. Ten minutes prior to his estimated arrival over Bear Lake he advised the communicator of his position and requested a clearance to proceed beyond this point, as his original clearance only covered his flight from Athens to Bear Lake. This clearance had already been sent by interphone by the Athens Airway Traffic Control Center, and the communicator transmitted it to Doe.

After passing over the Bear Lake station Doe advised the communicator of the time and altitude. This information was relayed to the Athens Airway Traffic Control Center for recording on the flight control board. Fifteen minutes later Doe was approaching Valley and began his descent from 11,000 feet in order to be at the right altitude to start his landing.

His calculations were correct for as he broke out underneath the clouds at 2,000 feet, 18 minutes later, he saw Kayne Bridge, a prominent landmark 16 miles south of Valley Airport, to his right. Doe then tuned his receiver to the Valley Tower frequency, for he could now control the aircraft with visual reference to the ground and no longer needed to follow the radio range.

After radio contact had been established with the tower, Doe notified the control tower operator of his position and altitude:

"VALLEY TOWER THIS IS STINSON ONE TWO THREE FOUR OVER KAYNE BRIDGE FOUR ONE AT TWO THOUSAND, OVER."

The words "FOUR ONE" gave the time of his position report, in minutes after the hour.

The tower cleared him to the traffic pattern as follows:

"STINSON ONE TWO THREE FOUR THIS IS VALLEY TOWER, KAYNE BRIDGE FOUR ONE AT TWO THOUSAND, CLEARED TO ENTER TRAFFIC PATTERN, WIND NORTHEAST ONE FIVE, RUNWAY FOUR, OVER."

Doe answered:

"STINSON ONE TWO THREE FOUR, ROGER",

which meant that he had received the instructions and information. As he came within sight of the airport control tower, the controller advised him of local traffic:

"STINSON ONE TWO THREE FOUR TWO MILES SOUTH, YOU ARE NUMBER TWO TO LAND, AMERICAN DOUGLAS EAST OF THE FIELD AHEAD OF YOU."

This meant that he could expect to be cleared to land after the Douglas had completed its landing. Shortly after, Valley Tower cleared Doe to land. By this time he had circled the field and was in position for final descent.

After he had landed, the tower gave Doe the following taxi instructions:

"STINSON ONE TWO THREE FOUR CLEARED TO GATE FOUR WATCH FOR MOWING EQUIPMENT TO THE WEST OF THE NORTH-SOUTH TAXI STRIP."

Doe answered:

"STINSON ONE TWO THREE FOUR ROGER OUT,"

and kept his receiver tuned to the tower frequency for any emergency instructions, until he had reached the gate and shut off the motor.

The control tower operator notified Airway Traffic Control of his arrival. This information completed the record of the flight and will be kept on file for reference if necessary. At no time had he been out of contact with one of the ground agencies, and the Athens Airway Traffic Control Center. During the entire flight he had used the navigational radio aids, and the Air Traffic Control services, in so doing protecting himself and other pilots flying the same course.

CONCLUSION

The flight just described represents a normal or routine case. The pilot on such a flight should take every precaution, however, which might prove helpful in an emergency. Most important of all (as already pointed out), radio should be considered as an AID to dead reckoning—not as a substitute for it. In the event of radio failure, either in transmission or reception, the pilot who has failed to keep an accurate log of heading, drift, and ground speed, is left without any dependable information on which to base his plans.

For flights wholly within the United States it is hardly likely that navigation other than a combination of dead reckoning and radio will ever be required (unless for practice). For transocean and other comparable flights, the good navigator will want to use everything. For example:

1. Use of a radio beam directed out to sea, for the first leg of the flight; or

2. Homing flight away from a radio beacon station;

3. A star (or sun) sight as soon as cruising altitude has been reached, using the point of departure as the assumed position;

4. Determination of actual wind by double drift at intervals of 30 or 60 minutes, if possible; if not, from a series of fixes from celestial or radio observations;

5. Radio cross bearings, whenever a station is available;

6. Celestial fixes from 3-star observations as frequently as practical;

7. A star (or sun) sight as the destination is approached, using the destination as the assumed position in order to check the distance still to go, and the ETA.

All these will be used by the careful navigator singly and in combination. At all times the probable error in a succession of fixes should be considered and allowed for. In the event of becoming temporarily lost, it is very important to maintain a constant heading until the position can be identified by some means. In contact flying, this affords some idea of the angle at which one may expect to cross streams, railroads, and other charted features; in instrument flying, even though no landmarks can be seen, it is just as essential. There is no surer way of getting hopelessly lost, even with good visibility, than circling aimlessly about in search of some feature that can be identified. In a short while the sense of direction becomes so confused that even familiar features are not recognized.

It has been said that the good navigator is one who distrusts all observations except a sight of the landing field. Two final rules might be stated, which apply to all phases of navigation and flying:

1. Take nothing for granted.

2. Plan ahead; consider all the things that may happen, and know what to do in each case.

Chapter XIII.—APPENDIX

ABBREVIATIONS AND SYMBOLS

In the solution of navigational problems and the tabulation of data, the use of suitable abbreviations saves time and affords greater clarity. The following abbreviations are often used and will be found very convenient in practice:

a = Altitude difference (intercept).
AA = Air Almanac.
A/C = Astro compass.
alt = Altitude or elevation above sea level.
ANRA = Air Navigation Radio Aids.
AP = Airport.
AS = Air speed.
ATC = Airway Traffic Control Center.
Bn = Beacon.
C = Convergence.
CAR = Civil Air Regulations.
CAS = Calibrated air speed.
CC = Compass course.
CFR = Contact flight rules.
CH = Compass heading.
Ck. pt = Check point.
corr = Correction.
D = Drift angle.
d_o = Distance out (radius of action).
D/Dr = Double drift.
Dec = Declination.
Dev = Deviation.
D/F = Direction finding.
D/G = Directional gyro.
DR = Dead reckoning.
DRM = Direction of relative movement.
E = Earth (origin or starting point).
ETA = Estimated time of arrival.
FHA = Fuel hours available (same as T).
FM = Fan marker, radio.
ft/min = Feet per minute.
G = Greenwich.
gal = Gallons.
GCT = Greenwich civil time.
GHA = Greenwich hour angle.
GS = Ground speed.
GS_o = Ground speed out.
GS_b = Ground speed back.
GST = Greenwich sidereal time.
H_c = Computed altitude (from assumed or DR position).
H_o = Observed altitude (sextant altitude corrected for refraction, etc.).
H_s = Sextant altitude (uncorrected).
I/A = Instrument approach.
IAS = Indicated air speed.
IC = Index correction.
IFR = Instrument flight rules.
Jc = Junction.
Kt = Knot.
Lat = Latitude.
L/D = Let-down, point of.
LHA = Local hour angle.
Long = Longitude.

LOP = Line of position.
M = Meridian of observer.
MC = Magnetic course.
metro = Meteorological.
MH = Magnetic heading.
mph = Miles per hour.
MRM = Miles of relative movement.
n. mi = Nautical miles.
P = Plane's position (in wind triangle).
P/A = Pressure altitude.
Par = Parallax.
P/I = Point of interception.
RA = Right ascension.
R/A = Radius of action.
R/B = Relative bearing.
Rbn = Marine radiobeacon.
RC = Radio compass (naval radio direction finder station).
R/C = Rate of climb.
R/D = Rate of descent.
R/D_p = Rate of departure.
Ref = Refraction.
RH = Homing radio beacon.
RM = Radio marker beacon.
R/R = Rate of return.
R Ra = Radio range station.
RS = Radio station (commercial broadcast).
SD = Semidiameter.
SHA = Sidereal hour angle.
SP = Seaplane port.
SRM = Speed of relative movement.
St. mi = Statute miles.
T = Total time (same as FHA).
TA = True altitude.
TAS = True air speed.
TC = True course.
TH = True heading.
T/I = Time of interception.
t_o = Time out (time to turn).
Tr = Track.
Var = Variation.
W = Wind (direction and velocity).
WC = Wind correction angle.
WNA = Weekly Notice to Airmen.
Z = Azimuth or bearing.
☽ = Moon.
✳ = Star.
☉ = Sun.
♈ = Vernal equinox (first point of Aries).
° = Degree sign.
′ = Minute sign (arc).
″ = Second sign (arc).

GLOSSARY OF PRINCIPAL NAVIGATIONAL TERMS

Airport, control.—An airport designated as having control over all traffic within a radius of 8 miles. If the associated radio range station is more than 2½ miles from the airport, the controlled zone includes a strip ½ mile on each side of the center line between them.

Airport of entry.—An airport through which air traffic may be cleared to or from a foreign country; aircraft making an international flight must take off from and land at such an airport, to comply with customs regulations.

Airport traffic control.—The control of local traffic in the vicinity of an airport by the airport management.

Air speed.—The velocity of an aircraft with respect to the air.

Air speed indicator.—An instrument for indicating the air speed of an aircraft.

Airway, civil.—A strip of land, together with the navigable air space above it, and the various air navigation aids, 5 miles on either side of the center line connecting the designated terminals and intermediate points, and extending 5 miles in all directions beyond the terminal airports.

Airway traffic control.—The control of traffic on the airways, exercised by Federal personnel.

Alternate airport.—An airport other than the point of first intended landing, specified in the flight plan, and to which the flight may be directed in emergency.

Altimeter.—An instrument for registering the altitude of an aircraft, usually in terms of feet above sea level. By adjustment of the barometric scale (on instruments so equipped), the altitude above a particular airport, or other point, may be indicated.

Altimeter setting.—The setting to be made to the barometric scale of an altimeter, such that, upon landing, the pointers of the instrument will indicate very closely the actual elevation of the airport above sea level.

Altitude.—The height of an airplane, usually expressed in feet above sea level. *Indicated a.* is that shown on the face of the instrument with the barometric scale set for the current altimeter setting; *pressure a.* is that indicated with the barometric scale set for the standard sea-level pressure of 29.92 inches; *true a.* is the pressure altitude corrected for temperature.

Altitude, absolute.—The height of an aircraft above the ground, obtained by radio altimeter, or by subtraction of the surface elevation from the altitude of flight.

Altitude curve.—A series of altitudes of a celestial body, precomputed for the predicted dead reckoning positions and plotted against time, as a graph; from it, the computed altitude for any given instant during flight may be obtained by inspection.

Altitude difference.—The difference between the computed altitude and the observed sextant altitude after all necessary corrections have been applied.

Altitude, sextant.—The angle of elevation of a celestial body above the horizon.

Approach channel.—The air space from the surface up to 17,000 feet, located within 2 miles on either side of the center of a radio range beam, usually for a distance of 15 miles from the station.

Aries, first point of.—The intersection of the celestial equator and the ecliptic; the vernal equinox. It is the origin of the celestial coordinates of right ascension and sidereal hour angle, and is usually referred to simply as "Aries."

Astro compass.—An instrument for indicating direction from celestial bodies, when properly adjusted for the position of the star and the approximate position of the observer.

Azimuth.—See "direction."

Barometer, aneroid.—An instrument indicating atmospheric pressure mechanically, by means of a resilient pressure chamber from which most of the air has been exhausted.

Barometer, mercurial.—An instrument indicating atmospheric pressure in terms of the height in inches or in millimeters of the column of mercury supported by it in an evacuated glass tube.

Beam bracketing.—The process of finding and, by a series of turns, determining the heading necessary to follow the right edge of a radio beam. Each pair of turns is considered as a "bracket," and each successive bracket is expected to be reduced about one-fourth.

Bearing.—See "direction."

Beaufort scale.—A scale for estimating wind velocities by noting the visible effects of the wind.

Bent courses.—Radio range courses deflected from their normal straight path because of topographic or other physical irregularities.

Bisector, average.—The average of the bearings of the individual bisectors of two opposite quadrants of a radio range station.

Chart, aeronautical.—A small scale representation of the earth, its culture, relief, and the various aeronautical aids; designed with special consideration for the needs of air navigation.

Chart, weather.—A chart, usually of small scale, for representing weather conditions and trends throughout the charted area.

Chronometer.—An accurate clock or watch, often with special conveniences for use in navigation.

Circle, great.—The intersection with the earth's surface of any plane passing through the center of the earth.

Circle, small.—The intersection with the earth's surface of any plane which does not pass through the center of the earth.

Circle of position.—A circle drawn around the point on the earth directly beneath a star or other heavenly body, from all points of which the altitude of the body is the same.

Civil Air Regulations.—The regulations prescribed by the Civil Aeronautics Board for the regulation and promotion of the many phases of aviation.

Civil airway.—See "airway."

Climb.—That period of flight during which an aircraft is climbing to its intended cruising altitude; generally expressed in feet per minute, measured by a rate-of-climb indicator.

Compass compensation.—The systematic reduction of compass deviation by inserting or adjusting small magnets incorporated in a magnetic compass for that purpose.

Compass, magnetic.—An instrument indicating magnetic directions by means of a freely suspended compass card; the primary means of indicating the heading or direction of flight of an aircraft.

Compass, radio.—See "radio."

Compass rose.—A circle, graduated in degrees from 0 to 360, printed on aeronautical charts as a reference to directions, true or magnetic.

Compass testing platform.—A suitable platform at principal airports, designed for checking the directions indicated by the compass of an aircraft against known magnetic directions, and so determining the error, or deviation, of the compass; also called a "compass rose."

Computer, aeronautical.—A mechanical device for graphic solution of wind triangles and other problems of dead reckoning, including speed-time-distance problems.

Cone of silence.—A limited area, shaped like an inverted cone, directly above the towers of a radio range station, in which the range signals are not received.

Contact flying.—Flight of an aircraft in which the attitude of the aircraft and its flight path can at all times be controlled by visual reference to the ground or water, within the prescribed minimums of ceiling and visibility.

Contour.—An imaginary line formed by the intersection of a horizontal plane with the surface of the earth, all points on any given contour being at the same elevation with respect to sea level (or other chosen reference plane).

Contour interval.—The vertical separation between the horizontal planes of two adjacent contours.

Control airport.—See "airport."

Control zone.—The air space above an area within 3 miles of the center of a control airport, and within one-half mile of a line from the center of such airport to the associated radio range station.

Control zone of intersection.—The air space within 25 miles of a radio range station designated as the center of such zone.

Convergence.—The angle between meridians on the surface of the earth, varying as the sine of the latitude, from 0 at the equator to 1° per degree of difference in longitude at the poles.

Also, the angle between meridians of the Lambert projection, which varies according to the standard parallels selected for the latitude band under consideration.

Coriolis effect.—The effect of the earth's rotation, which causes bodies in motion to be deflected to the right in the northern hemisphere, to the left in the southern hemisphere.

Course.—See "direction."

Cruise.—That portion of a flight conducted at a constant altitude.

Cruise control.—Determination of the most favorable flight level for a particular aircraft under specific conditions, and of the cruising radius of the aircraft.

Culture.—Generally applied to the cities, railroads, highways, and other constructed features on the surface of the earth; often referred to as "the works of man."

Danger curve.—A dotted line on aeronautical charts outlining an area within which it is dangerous for seaplanes to land; usually the 6-foot depth curve.

Dead reckoning.—See "navigation."

Declination.—The angular distance of a celestial body north or south of the celestial equator.

Declination, magnetic.—Engineering term for magnetic variation.

Descent.—That period of flight during which an aircraft is descending from its cruising altitude; usually expressed in feet per minute, measured by a rate-of-climb indicator.

Deviation.—The error of a magnetic compass due to magnetic influences in the structure and equipment of an aircraft.

Deviation card.—A card recording the deviations of a particular compass and indicating the compass direction corresponding to any desired magnetic direction.

Dip.—In celestial navigation, the error introduced when the natural sea horizon is viewed from altitudes above the surface of the sea.

Direction:

> *Azimuth.*—The initial direction of the arc of a great circle; the angle between the plane of the great circle and the meridian of the place. As used in air navigation it is measured from the north, in a clockwise direction, from 0° to 360°.
>
> *Bearing.*—In air navigation, the same as azimuth.
>
> *Course.*—The direction of the rhumb line, or the line of constant direction. As used in air navigation with the Lambert projection, it is measured at the meridian nearest halfway between the starting point and destination.
>
> *Heading.*—The direction in which the airplane is pointed, in contradistinction to its path over the ground.
>
> *Track.*—The rhumb-line direction of the actual flight path of an aircraft over the ground.
>
> All the above directions may be true, magnetic, or compass, according as they are referred to true north, magnetic north, or compass north.
>
> *Wind.*—Always the true direction *from* which the wind blows.

Directional gyro.—An instrument which maintains for a limited time, by gyroscopic means, any direction for which it may be set.

Dividers, spacing.—Multiple-point dividers, so constructed that a line between its extreme points is always divided into 10 equal parts.

Drift angle.—The angle between the heading of an aircraft and its track, or flight path over the ground.

Drift, double.—A method for determining the direction and velocity of the wind by means of the drift angles observed on two headings at right angles to each other.

Drift sight.—An instrument for determining the angle of drift; often accomplished by observing the apparent motion of points on the earth's surface along a grid incorporated in the instrument.

Earth.—One of the nine known planets comprised in the solar system.

Ecliptic.—An imaginary line on the celestial sphere, traced by the intersection of the sphere with the plane of the earth's orbit.

Elevation.—The vertical height above sea level, of a point on the earth's surface.

Ellsworth point.—In celestial navigation near the poles, a point used in correcting a line of position for its departure from the corresponding circle of position.

Equator, celestial.—The intersection of the earth's equator, extended, and the celestial sphere.

Equator, magnetic.—An imaginary line on the earth's surface, approximately halfway between the magnetic poles of the earth.

Equator, terrestrial.—An imaginary line formed by the intersection of the earth's surface and a plane perpendicular to the earth's axis at its middle point.

Equinox, vernal.—See "Aries, first point of."

Equisignal zone.—The zone within which signals from two adjacent quadrants of a radio range station may be heard with equal strength.

Fading.—Diminishing of signal strength because of increasing distance from a radio station, or because of other radio phenomena.

Fix.—A definite position of an aircraft, determined by the intersection of two or more bearings or lines of position, or by other means.

Fix, radio.—A geographical location on a civil airway above which the position of an aircraft in flight can be accurately determined by radio alone (such as a Z marker beacon, fan marker, or intersection of two radio beams).

Fix, running.—A fix obtained by moving forward the first of two lines of position the distance and direction made good between the taking of two observations, to intersect with the second line of position.

Flight check.—The correction of the details of an aeronautical chart, by comparison in flight with the ground beneath.

Flight plan.—A statement of the essential information for a proposed flight, which must be submitted to and approved by the airway traffic control center, for all flights other than contact flying.

Gnomonic.—A chart projection on which all great circles are exactly represented by straight lines.

Greenwich.—The location of the principal British observatory, near London. In most countries, longitude is reckoned east or west from the meridian passing through this observatory.

Ground speed.—The speed of an aircraft with reference to the surface of the earth.

"G" system.—A system of directions proposed for use in polar areas, under which all directions are referred to a series of grid lines parallel to the meridian of Greenwich. The direction from Greenwich to the pole is considered as 000°.

Heading.—See "direction."

Homing.—Flight toward or away from a radio station, using a radio compass (or equivalent) as a primary means of maintaining direction.

Horizon, artificial.—A gyro-stabilized instrument providing a horizontal reference for aircraft in instrument flight.

In celestial navigation, the horizon obtained by means of a spirit level incorporated in the optical system of a bubble sextant.

Horizon, natural.—The horizon line where sea and sky seem to meet.

Hour angle:

> *Greenwich.*—The difference of longitude between the meridian of Greenwich and the meridian of a celestial body. Measured from Greenwich toward the west, up to 360°
>
> *Local.*—The difference of longitude between the meridian of the observer and the meridian of a celestial body; usually measured from the meridian of the observer toward the east or west, from 0° to 180°.
>
> *Sidereal.*—The difference of longitude between the meridian passing through the vernal equinox and the meridian of a celestial body. Measured from the vernal equinox toward the west, up to 360°.

Instrument approach.—An approach to an airport by instruments and radio guidance, designed to break through an overcast within the required weather minimums, and to permit a landing after break-through by visual contact.

Instrument flying.—Flight of aircraft in which visual reference is not continuously available and the attitude of the aircraft and its flight path can be controlled in part or in whole by reference to instruments only.

Intercept.—In celestial navigation, the difference between the observed and computed sextant altitudes of a celestial body.

Interception.—The problem of determining the direction of flight, the direction and speed of relative movement, and the time required to intercept another craft in motion.

Isogonic line.—An imaginary line on the surface of the earth at all points on which the magnetic variation is the same.

Knot.—A velocity of one nautical mile per hour.

Lambert.—The name of the chart projection used as a base for aeronautical charts of the Coast and Geodetic Survey. Straight lines on this projection closely approximate great circles, and distances may be measured with a high degree of accuracy.

Lambert equal area.—Another chart projection devised by Lambert, used for certain weather charts of the Army Air Forces.

Latitude.—Distance north or south of the equator, measured in degrees, minutes, and seconds of arc.

Legend.—The marginal written notes and pertinent information, which are intended "to be read."

Line of position.—A short section of a circle of position; in reality, a tangent to a circle of position, constructed through the assumed position, which is at the end of a radius from the center of the circle.

Line of position, radio.—A line from a radio station, from all points of which the bearing of the station is the same.

Localizer, airport.—May be thought of as a low-powered radio range, at least one beam of which passes over an airport to which it serves to direct traffic; usually of very high frequency (VHF), and with two courses instead of four.

Longitude.—The distance along the equator between the meridian passing through a place and (usually) the meridian of Greenwich; measured in degrees, minutes, and seconds of arc.

Magnitude (of a star).—The relative brightness of a star according to a fixed standard of measurement. Each magnitude is 2½ times as bright as the next fainter magnitude.

Mercator.—The chart projection commonly used for nautical charts. On this projection the rhumb line is represented by a straight line; great circles (radio bearings are great circles) are represented by curved lines. Due to the rapidly expanding scale, distances must be measured with the scale for the middle latitude between the two points in question. It is also used for aeronautical charts near the equator, for the long range navigation charts of the Army Air Forces, and for the aeronautical charts of the Navy.

Mercator equal area.—Another projection devised by Mercator, used for certain weather charts of the Air Forces.

Mercatorial bearing.—A radio bearing is converted from a great-circle direction to a rhumb-line direction ("Mercatorial bearing") for plotting on a Mercator chart.

Meridian, true or geographic.—Any of the great circles passing through the geographic poles of the earth.

Meridian, magnetic.—The great circle the plane of which makes an angle with the plane of the true meridian equal in direction and magnitude to the magnetic variation of a place.

Meridian, prime.—The meridian which serves as the origin from which longitude is reckoned; in most countries this is the meridian of Greenwich.

Meridian altitude.—The altitude of a celestial body, observed (or computed) as it passes over (transits) the meridian of the observer. It furnishes one of the simplest methods for the determination of latitude.

Mile, nautical.—The ordinary unit of 6,080.20 feet (1,853.25 meters) for measuring distances at sea. For practical purposes a minute of latitude may be considered as equal to a nautical mile. It is approximately equal to 1.15 statute miles.

Mile, statute.—The ordinary unit of 5,280 feet for measuring distances on land. It is approximately equal to 0.87 nautical miles.

Millibar.—A unit of barometric pressure, 1,000 millibars being equal to 29.53 inches of mercury; conversely, 1 inch of mercury is equal to 33.86 millibars.

Multiple courses.—A number of narrow equisignal zones resulting from the breaking up of a radio range course by mountainous topography or other causes.

Navigation:

> Celestial.—The determination of position by means of sextant observations of the celestial bodies, together with the exact time of observation.
>
> Dead reckoning.—The determination of the distance and direction between two known points, or the determination of position from a knowledge of the distance and direction from a known point.
>
> Pilotage.—Directing an airplane with respect to visible landmarks.
>
> Radio.—The determination of position by means of observed radio bearings.

Night effect.—Variation in the positions of the radio range courses, or displacement of a radio bearing due to interference from reflected sky waves or other causes peculiar to night conditions.

North, magnetic.—The direction indicated at any place by the needle of a magnetic compass undisturbed by local magnetic attraction.

North, true.—The direction of the north geographic pole.   ·

No-wind position.—The position at which an aircraft would be at any given time, as a result of the distance and direction of its flight, if there had been no wind.

Octant.—An instrument similar to the sextant, except that the arc by means of which the altitude is measured is only an eighth of a circumference (instead of a sixth); usually referred to as a "sextant." .

Orientation.—In radio navigation, a method of determining position relative to the quadrants and equisignal zones of a radio range station; or of determining position relative to a radio station by means of radio compass or direction finder.

Over-the-top flight.—Flight of aircraft above an overcast, usually a cloud formation.

Parallax.—In air navigation, the angle at the moon between lines to the observer's position and to the center of the earth.

Parallel.—The intersection of the earth's surface with a plane parallel to the equator.

Parallel, standard.—One of the two standard parallels of a Lambert projection along which all distances are true; a parallel of true scale in any projection.

Pelorus.—A circular bearing plate, graduated in degrees, which may be used to determine the true or relative bearings of objects.

Point of no return.—The point beyond which an aircraft has insufficient fuel to return to its starting point.

Pole, celestial.—The point on the celestial sphere intersected by the extension of the earth's axis.

Pole, magnetic.—A point on the earth where a freely suspended magnetic needle would point vertically. The north magnetic pole is located at about latitude 71° north, longitude 96° west; the south magnetic pole about latitude 73° south, longitude 156° east.

Pole, geographic.—The intersection of the earth's axis with the surface of the earth.

Precomputed altitude curve.—See "altitude curve."

Projection.—The system of reference lines representing the earth's meridians and parallels on a chart. The projection is usually designed to retain some special property of the sphere, as true directions, true distances, true shape, or true area.

Protractor.—A device for measuring angles; usually associated with a straightedge for drawing the angle measured.

Radio.—The call to be used when calling a radio range station; as "Jacksonville radio, this is Stinson 1234."

Radio altimeter.—A device for measuring the height of an aircraft above the surface of the earth (not above sea level), by means of reflected radio waves.

Radio beam.—See "equisignal zone."

Radio compass.—A device employing a fixed loop antenna and visual indicator; used chiefly for "homing" flight (flight directly toward or away from a radio station).

Radio direction finder.—A device similar to the radio compass, but employing a rotatable loop antenna; signals are often received both aurally and visually.

Radio direction finder, automatic.—Similar to the ordinary radio direction finder, except that rotation of the loop is automatic, and the indicator needle continuously indicates the bearing of the station.

Radio direction finder station.—A ground station (or group of stations) equipped to determine the directional bearing (or position) of craft from the station, and reporting the results to the navigator by radio.

Radio fix.—See "fix, radio."

Radius of action.—The distance or time an aircraft may safely fly toward its destination before turning back to the starting point or to some alternate airport.

Range.—An alignment of landmarks along a route such that the desired track may be made good by flying so as to keep the objects continually in line.

Range approach channel.—See "approach channel."

Rate of climb indicator.—An instrument indicating the rate of ascent or descent of an aircraft, usually in feet per minute. Often called (more accurately) a vertical speed indicator.

Reciprocal.—Any given direction (whether course, bearing, or heading) plus or minus 180°.

Rectifying.—The process of removing from the compass heading observed in flight the errors due to deviation, variation, and wind.

Refraction.—The bending of the line of sight from a celestial body by the earth's atmosphere, as a result of which the observed altitude of the body always appears higher than the true altitude.

Relative bearing.—The bearing of a radio station or object relative to the airplane's head.

Relative movement.—The movement of an aircraft relative to another craft also in motion.

Relative wind.—A fictitious wind, the resultant of the actual wind and the motion of the craft to be intercepted, in problems of interception.

Relief.—The inequalities in elevation of the surface of the earth; represented on the aeronautical charts by contours and gradient tints. Elevations are generally expressed in feet above mean sea level, the one exception on aeronautical charts being that the shore line is the line of high water.

Restricted areas.—Areas within which flight is restricted or prohibited. as follows:

    Caution area.—An area in which a visible hazard to flight exists; to be avoided if practicable.

Danger area.—An area in which invisible hazards exist; all flying prohibited unless authorized by the agency having jurisdiction over the area.

Prohibited area.—An area established by the President, in which all flight is prohibited except for aircraft actually engaged in defense missions.

Range approach channel.—See "approach channel."

Traffic tunnel.—An area within which flight is restricted between fixed limits horizontally, and between maximum and minimum altitudes vertically.

Rhumb line.—A curved line ("loxodromic spiral") on the surface of the earth, crossing all meridians at a constant angle.

Right ascension.—In celestial navigation, the distance of a body on the celestial sphere from the vernal equinox; measured toward the east, from 0^h up to 24^h; corresponds to longitude on the terrestrial sphere.

Scale.—A statement of the proportion existing between a chart and the region charted; usually stated as 1:1,000,000; as 1:5,000,000, and the like.

Sextant.—An instrument used in celestial navigation for determining the altitude of a celestial body above the horizon.

Sinusoidal.—Another name for the Mercator equal area projection.

Standard parallel.—One of the two parallels of latitude at which the cone representing a Lambert projection band intersects the sphere; in any projection, a parallel along which the scale is true.

Stereographic.—A chart projection used in air navigation chiefly for charts of the polar areas, where it possesses the same properties as the Lambert projection in lower latitudes.

Teletype.—A system of communications by automatic typewriters, operated by wire, or by radio. Extensively used by the Civil Aeronautics Administration in transmitting weather data and other flight information.

Terrain clearance indicator.—See "radio altimeter."

Time, civil.—Time measured by the rotation of the earth with respect to the mean sun.

Time, mean.—See "time, civil."

Time, sidereal.—Time measured by the rotation of the earth with respect to the vernal equinox.

Time, standard.—The civil time adopted as standard within a zone approximately 15° of longitude in width.

Time signals.—Precise signals transmitted by radio to provide navigators and others with the exact time. In the United States this service is rendered by the U. S. Naval Observatory and by the National Bureau of Standards.

Tower.—The call to be used when calling an airport control tower; as "Jacksonville tower, this is Stinson 1234."

Tower, airport control.—The communication center through which pilots receive traffic instructions from the local airport management and from the Federal airway traffic control center, and to which they report the required flight information.

Track.—The actual flight path of an aircraft over the ground.

Tracking.—Plotting on the chart the continuous series of positions (track) of an aircraft from a knowledge of the direction and velocity of the aircraft and of the wind.

Twilight:

   Astronomical.—The twilight glow which exists when the sun is not more than 18° below the horizon, either at evening or in the morning. When the sun is more than 18° below the horizon, the faintest stars ordinarily visible can be seen.

   Civil.—The period when the sun is between the horizon and a point 6° below the horizon. It is civil twilight that is tabulated in the Air Almanac.

Variation, magnetic.—The angle between true north and magnetic north at any given place.

Wind angle.—The angle between the true course (or the heading, as the case may be) and the direction from which the wind is blowing; measured from the true course (or the heading) toward the right or left, from 0° up to 180°.

Wind correction angle.—The angle at which an aircraft must be headed into the wind in order to make good the desired track.

Wind direction.—See "direction, wind."

Wind star.—A graphic solution for the direction and velocity of the wind by plotting the drift angles observed on two or more headings approximately at right angles.

Zenith.—The point on the celestial sphere directly over the head of the observer.

Zone of intersection.—That part of a civil airway which overlaps and lies within any part of any other civil airway.

PRICE LIST OF AERONAUTICAL CHARTS

All aeronautical charts of the United States published by the Coast and Geodetic Survey may be obtained from the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C., or from one of the following regional offices:

Hudson Terminal Building, 50 Church St., New York.
Customhouse, Boston, Mass.
423 Canal Street, New Orleans, La.
1001 Monticello Avenue, Norfolk, Va.
Post Office & Courthouse, Los Angeles, Calif.
Customhouse, San Francisco, Calif.
Insurance Building, Seattle, Wash.
502-3 Panama Building, Portland 4, Oreg.

Authorized agents have again been appointed throughout the United States for the distribution of aeronautical charts. A list of these agents, with the dates of latest prints of charts, will be printed from time to time in the Weekly Notice to Airmen. This information may also be obtained from the Director, U. S. Coast and Geodetic Survey.

Prices of charts for single copies are as follows:

Aeronautical planning charts (scale 1:5,000,000) 40 cents.
Radio direction finding charts (scale 1:2,000,000) 40 cents.
Regional charts, United States and Alaska (scale 1:1,000,000) 40 cents.
Sectional charts (scale 1:500,000) 25 cents.
Local charts (scale 1:250,000) 25 cents.
Airport charts of principal civilian airports (for instrument approach and landing; see p. 11) 10 cents.
Great-circle chart No. 3074a (scale approximately 1:5,000,000) 40 cents.
Magnetic chart of the United States, No. 3077 (scale approximately 1:7,500,000) 20 cents.
Air-line distances chart, United States (scale 1:5,000,000) 40 cents.
Aeronautical wall map (planning chart of the United States, enlarged to 1:3,000,000; in 2 sheets, size of complete map 44 x 66 inches) $1.00.

A discount of 33⅓% from full published prices is allowed on aeronautical and auxiliary charts amounting to $10 gross when made in one shipment to one address. Charts are not returnable.

PUBLICATIONS OF THE CIVIL AERONAUTICS ADMINISTRATION

Listed in the following are the available publications of the Civil Aeronautics Administration which may be of interest to pilots. The sales price, if any, of each publication is given after the title. A complete list of all publications may be obtained from the Civil Aeronautics Administration.

The publications for which there is a charge must be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Others may be obtained from Information and Statistics Service, Civil Aeronautics Administration, Washington 25, D. C.

The rules of the Superintendent of Documents require that remittances be made in advance of shipment of publications, either by coupons, sold in sets of 20 for $1 and good until used, or by check or money order payable to the Superintendent of Documents. Currency may be sent at senders' risk. Postage stamps, foreign money, or smooth coins are not acceptable. A discount of 25 percent is allowable to book dealers and quantity purchasers of 100 or more publications, on condition that the purchaser will adhere to the public sales price set by the Superintendent of Documents and that publications shall not be overprinted with any advertising matter.

CIVIL AERONAUTICS JOURNAL

This is the official periodical of the Civil Aeronautics Administration. Published on the 15th of each month, it carries articles and news items on civil aeronautics. News of activities of the Civil Aeronautics Administration are emphasized but other information is carried, particularly statistical material on scheduled air carriers, private operations, and aircraft manufacturing. A special section of the JOURNAL is devoted to official actions of the Civil Aeronautics Board. Considerable emphasis is also given to aircraft accident reports. Subscription price of the CIVIL AERONAUTICS JOURNAL is 50 cents a year in the United States. Foreign subscriptions are 75 cents a year. Single copies are 5 cents each.

CIVIL AERONAUTICS BULLETINS

No. 5. Flight Instructors' Manual. 35 cents.
No. 22. Digest of Civil Air Regulations for Pilots. 20 cents.
No. 23. Civil Pilot Training Manual. 65 cents.
No. 24. Practical Air Navigation. $1.
No. 25. Meteorology for Pilots. 75 cents.
No. 26. Aerodynamics for Pilots. 30 cents.
No. 27. Pilots' Airplane Manual. 30 cents.
No. 28. Pilots' Powerplant Manual. 75 cents.
No. 31. Patter for Elementary Flight Maneuvers. 15 cents.
No. 32. Fundamentals of Elementary Flight Maneuvers. 20 cents.

MISCELLANEOUS

Aeronautical Statutes and Related Material. 15 cents.
Army-Navy-Civil Committee Reports:
    ANC–1 (1) Spanwise Air Load Distribution. 60 cents.
    ANC–1 (2) Chordwise Air Load Distribution.
    ANC–2   Ground Loads Handbook. 10 cents.
    ANC–5   Strength of Aircraft Elements. 35 cents.
    ANC–14   Spin Requirements for PT Airplanes.
Civil Aeronautics Act of 1938. Public, No. 706. 10 cents.
Obstruction Marking Manual.
Pilot's Written Examination Guidebook.

STANDARD TEXTS RELATED TO AIR NAVIGATION

Airlines War Training Institute:
    Blackburn, Elbert F. *Celestial Navigation.*
    Blackburn, Elbert F. *Navigation Principles.*
    Ford, John J. *Loading and Cruising.*
Alexander and Allan. *The Observer's Book on Dead Reckoning Navigation.*
Baker, Robert H. *An Introduction to Astronomy.*

Beij, K. Hilding. *Astronomical Methods in Air Navigation.* (National Advisory Committee for Aeronautics, Report No. 198).[1]

Bernhard, Bennett, Rice. *New Handbook of the Heavens.*

Bowditch, Nathaniel. *American Practical Navigator* (H. O. 9).[1,2]

Boxhall and Devereux. *Contours.*

Chichester, Francis. *The Observer's Book on Astro-Navigation; Parts I, II, III, and IV.*

Civil Aeronautics Administration. See page 343.

Deetz, Charles H., and Adams, Oscar S. *Elements of Map Projection* (U.S.C.&G.S. Special Publication No. 68).[1]

Dutton, Benjamin. *Navigation and Nautical Astronomy.*

Federal Communications Commission, U. S. *Study Guide and Reference Material for Commercial Radio Operator Examinations.*[1]

Gatty, Harold. *The Raft Book.*

Irvin, George Ellis. *Aircraft Instruments.*

McIntosh, Colin H. *Radio Navigation for Pilots.*

Mixter, George W. *Primer of Navigation.*

Navy Department, U. S.:

Bureau of Aeronautics—

Air Navigation:

Part   I. *Introduction to Earth.*
Part   II. *Introduction to Navigation.*
Part III. *Dead Reckoning and Lines of Position.*
Part IV. *Navigation Instruments.*
Part   V. *Relative Movement.*
Part VI. *Contact Flying.*
Part VII. *Nautical Astronomy and Celestial Navigation.*

Instrument Flight (Part One).

Hydrographic Office[1,2]—

H.O. 127.   *Star Identification Tables.*
H.O. 208.   *Navigation Tables for Mariners and Aviators (Dreisonstok).*
H.O. 211.   *Dead Reckoning Altitude and Azimuth Tables (Ageton).*
H.O. 214.   *Tables of Computed Altitude and Azimuth.*
H.O. 218.   *Air Navigation Tables (restricted).*
H.O. 2102c. *Rude Star Finder for Aviators.*
H.O. 2665a. *Maneuvering Board Diagrams (pad of 50).*

Naval Observatory—

The American Air Almanac.

Olcott, William Tyler *Field Book of the Skies.*

Redpath, Peter H., and Coburn, James M. *Air Transport Navigation.*

Tornich, Mary. *Radius of Action of Aircraft.*

War Department,[1] U. S.:

Air Navigation. Technical Manual TM 1–205.
Celestial Air Navigation. TM 1–206 (restricted).
Air Navigation Tables. TM 1–208.
Aircraft Instruments. TM 1–413.
Instrument Flying Training. TM 1–445.

Weems, P. V. H. *Air Navigation.*

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[1] For sale (unless restricted) by the Superintendent of Documents, Washington, D. C.
[2] For sale (unless restricted) by the Hydrographic Office, Washington, D. C.

INDEX